

# **Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-101**

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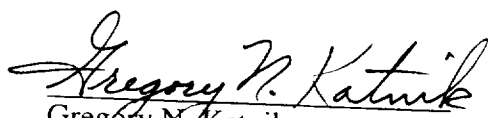
**DEBRIS/ICE/TPS ASSESSMENT  
AND  
INTEGRATED PHOTOGRAPHIC ANALYSIS  
OF  
SHUTTLE MISSION STS-101**

**19 May 2000**

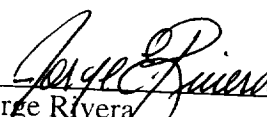
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# TABLE OF CONTENTS

TABLE OF CONTENTS.....	i
TABLE OF FIGURES.....	ii
TABLE OF PHOTOS.....	iii
FOREWORD.....	iv
1.0 SUMMARY OF SIGNIFICANT EVENTS .....	2
2.0 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION.....	4
3.0 SCRUBS.....	6
3.1 FINAL INSPECTION – WEATHER SCRUB 1 .....	6
3.2 POST DRAIN INSPECTION .....	8
3.3 FINAL INSPECTION – WEATHER SCRUB 2 .....	9
3.4 POST DRAIN INSPECTION .....	10
3.5 FINAL INSPECTION – WEATHER SCRUB 3 .....	11
3.6 POST DRAIN INSPECTION .....	13
4.0 LAUNCH.....	14
4.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION.....	14
4.2 FINAL INSPECTION .....	14
4.2.1 ORBITER .....	14
4.2.2 SOLID ROCKET BOOSTERS .....	15
4.2.3 EXTERNAL TANK.....	15
4.2.4 FACILITY .....	15
4.3 T-3 HOURS TO LAUNCH.....	15
5.0 POST LAUNCH PAD DEBRIS INSPECTION .....	22
6.0 FILM REVIEW.....	25
6.1 LAUNCH FILM AND VIDEO SUMMARY .....	25
6.1.1 VAPOROUS STREAK AT 34 SECONDS MET .....	26
6.2 SRB CAMERA VIDEO SUMMARY .....	27
6.2.1 -Y SIDE DIVOT COUNT.....	28
6.2.2 +Y SIDE DIVOT COUNT.....	28
6.3 ON-ORBIT FILM AND VIDEO SUMMARY .....	34
6.3.1 16MM FILM FOOTAGE.....	34
6.3.2 35MM FILM FOOTAGE.....	34
6.3.3 CREW HAND-HELD STILL IMAGES.....	35
6.4 LANDING FILM AND VIDEO SUMMARY .....	44
7.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT.....	45
8.0 ORBITER POST LANDING DEBRIS ASSESSMENT.....	49
APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY.....	A
APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY.....	B

## TABLE OF FIGURES

Figure 1: Orbiter Lower Surface Debris Damage Map.....	51
Figure 2: Orbiter Right Side Debris Damage Map .....	52
Figure 3: Orbiter Left Side Debris Damage Map.....	53
Figure 4: Orbiter Upper Surface Debris Damage Map.....	54
Figure 5: Orbiter Post Flight Debris Damage Summary.....	55
Figure 6: Control Limits for Lower Surface Hits.....	56
Figure 7: Control Limits for Total Hits.....	57

## TABLE OF PHOTOS

Photo 1: Launch of Shuttle Mission STS-101 .....	1
Photo 2: Pre-Launch Debris Inspection .....	5
Photo 3: Hairline Cracks in Intertank Stringer Valleys .....	7
Photo 4: Crack in +Y Longeron TPS .....	12
Photo 5: ET LO2 Tank and Intertank .....	16
Photo 6: LH2 Tank Acreage .....	17
Photo 7: Cracks in Intertank Stringer Valleys .....	18
Photo 8: ET +Y Longeron .....	19
Photo 9: ET +Y Longeron TPS .....	20
Photo 10: Overall View of SSME's .....	21
Photo 11: HDP #8 Blast Cover Coating .....	23
Photo 12: Aft Skirt GN2 Purge Lines .....	24
Photo 13: Ice Contacting SSME #3 Nozzle .....	29
Photo 14: Debris from RSS/FSS .....	30
Photo 15: Ice Impacting Orbiter Right Wing .....	31
Photo 16: Vaporous Streak from Right Wing .....	32
Photo 17: Large Flash in SSME Plume .....	33
Photo 18: ET -Y Thrust Panel .....	36
Photo 19: ET +Y Thrust Panel .....	37
Photo 20: Divot on -Z Side .....	38
Photo 21: Protruding Purge Seal .....	39
Photo 22: Loose O-Ring .....	40
Photo 23: ET After Separation .....	41
Photo 24: ET Intertank Area .....	42
Photo 25: ET Thrust Panels .....	43
Photo 26: Frustum Post Flight Condition .....	46
Photo 27: Forward Skirt Post Flight Condition .....	47
Photo 28: Aft Skirt Post Flight Condition .....	48
Photo 29: Overall View of Orbiter Sides .....	58
Photo 30: Damage to Lower Surface Tiles .....	59
Photo 31: LO2 ET/ORB Umbilical .....	60
Photo 32: LH2 ET/ORB Umbilical .....	61
Photo 33: Windows .....	62

## **FOREWORD**

The Debris Team has developed and implemented measures to control damage from debris in the Shuttle operational environment and to make the control measures a part of routine launch flows. These measures include engineering surveillance during vehicle processing and closeout operations, facility and flight hardware inspections before and after launch, and photographic analysis of mission events.

Photographic analyses of mission imagery from launch, on-orbit, and landing provide significant data in verifying proper operation of systems and evaluating anomalies. In addition to the Kennedy Space Center Photo/Video Analysis, reports from Johnson Space Center and Marshall Space Flight Center are also included in this document to provide an integrated assessment of the mission.

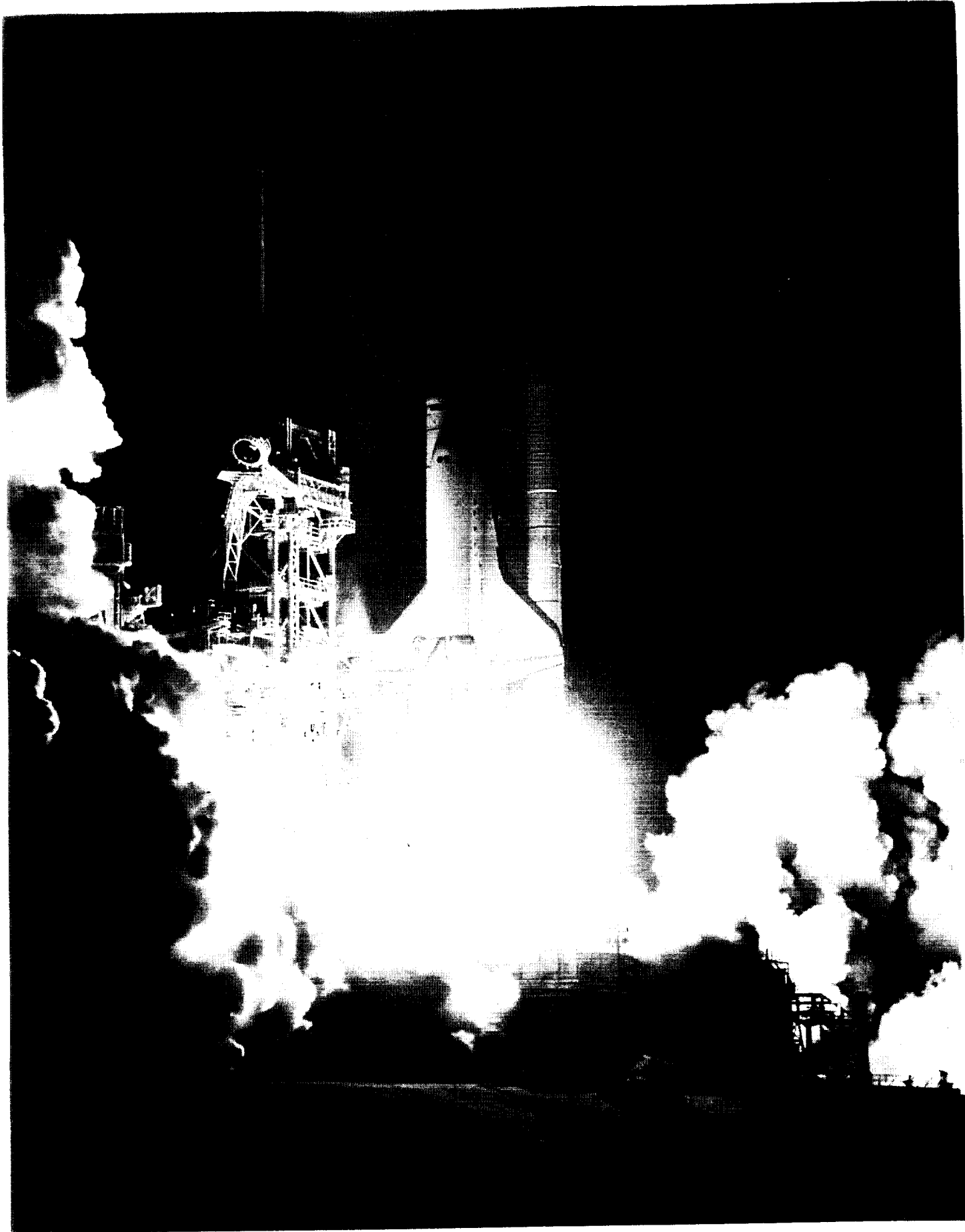


Photo 1: Launch of Shuttle Mission STS-101





## 1.0 SUMMARY OF SIGNIFICANT EVENTS

STS-101 consisted of OV-104 Atlantis (21st flight), ET-102, and BI-101 SRB's on MLP-1 and Pad 39A. Atlantis was launched at 10:11:10 UTC (6:11 a.m. local) on 19 May 2000. Landing was at 2:20 a.m. local/eastern time on 29 May 2000.

STS-101 was tanked four times, a record for the SLWT configuration. Generally speaking, the External Tank was in excellent condition for all loading and drain cycles. The only significant TPS issue involved two cracks in the +Y longeron closeout TPS since this condition was outside the NSTS-08303 guidelines. One crack was 4 inches in length by 3 inches wide by 1/8-inch wide in an inverted horseshoe shape. The second crack was horizontal, 2-inches long, and hairline in width. The two cracks were caused by thermal/mechanical induced stresses and localized defects in the thick BX-250 TPS closeout. A similar but more severe condition occurred on STS-99. That condition was approved for flight via MRB and essentially the same rationale was used for the TPS cracks on this vehicle.

One unusual debris issue was the detection of a small braided tether cable (metal) resting on the ET crossbeam the day before launch. The tether was estimated to be 5-6 inches in length, 1/16 to 1/8 inches in diameter, and a mass of 2 grams. The tether most likely fell from the upper levels of the RSS during platform securing operations prior to RSS rollback. Since the OWP's had been retracted already, no action to remove the tether was recommended based on the tether's minimal debris threat to the flight hardware. The aft location at XT-2048 was no worse than high density ice from the ET/ORB umbilicals near this location, and initial flight aerodynamic cross flow would push the tether outboard away from Orbiter tiles. As a worst case scenario with the tether moving toward tiles, there would be an insignificant aerodynamic acceleration due to the low cross-sectional frontal area resulting in little or no damage. MRB approved the condition to use as-is.

Post launch film review detected an impact from a debris object at 10:11:44.109 GMT on the Orbiter lower surface at a point that appeared to be about 8 feet forward of the right inboard elevon hinge. This event in turn caused a very visible "vaporous" streak to pass the trailing edge of the elevon.

The debris object was a 6-inch piece of ice from the ET LO2 feedline upper bellows. The ice disintegrated upon impact thereby comprising most of the material in the streak, though there may also have been some tile material as well from the damage site. After the impact, no damage site could be discerned. However, the film was grainy and individual tiles could be resolved. Therefore, the damage site was not extremely large, which would have been visible to some degree.

This streak was compared to a somewhat similar streak detected on STS-26R, which was the result of a debris impact that caused a tile damage site 18 inches long by 8 inches wide by 1.5 inches deep. However, the STS-101 streak was considerably less "dense" indicating a much smaller damage site. Shuttle Program management elected not to use the RMS for a tile survey due to lighting problems and poor resolution on such previous surveys. However, it was prudent to take some precautions anyway, so the Orbiter performed a thermal conditioning maneuver prior to re-entry to cold bias the right wing and elevon structure. This increased the temperature margin and, therefore, reduced the potential for structural damage. The detection of the debris impact and resulting damage site was not considered a Safety of Flight issue, but more of an R&R effort after landing.

Post landing inspection of Orbiter tiles showed a total of 113 hits, of which 27 had a major dimension of 1-inch or larger. The Orbiter lower surface sustained 70 total hits, of which 19 had a major dimension of 1-inch or larger. Some of these damage sites (23 hits with five larger than 1-inch) were located in the area from the nose gear to the main landing gear wheel wells on both left and right chines, which is consistent with the loss of foam from ET thrust panels. But the overall quantity and average size of the damage sites compared to previous flights were consequently reduced as a result of the pre-launch TPS venting modification. And some of the hits in this area may also be attributed to impacts from LO2 feedline bellows ice particles.

In general, the lower surface tile damage on this flight was considered to be a return to fleet averages, or "in family". Missions STS-86 through STS-103 are considered an "out of family" set due to the loss of TPS from External Tank thrust panels. With the incorporation of the successful - and full scale - TPS venting modification, missions flown after STS-103 will now be compared against the adjusted database and any data points outside the 3-sigma variation will be investigated as a new problem.

The largest lower surface tile damage site, located on the left wing immediately forward of the inboard elevon hinge, measured 8-inches long by 1.25-inches wide by 0.75-inches deep. The cause of this damage site has not been determined. However, it should be noted the damage site typically erodes during re-entry and may have initially been considerably smaller than the size listed above. Referencing the Debris Trajectory Database showed potential points of origin on the forward and mid segments of the left SRB, so it is possible a small piece of cork or BTA may have come loose in flight.

Likewise, a lower surface tile damage site on the right wing, approximately 10 feet forward of the right inboard elevon hinge, corresponded to the ice impact detected in launch films. The damage site measured 5.25-inches long by 1.5-inches wide by 0.5-inches deep, though re-entry erosion had enlarged this damage site as well. The composition of the "vaporious streak" detected in the launch films was a mixture of ice debris and damaged tile material particles.

## 2.0 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted at 0900 on 21 April 2000. The following personnel participated in various team activities, assisted in the collection and evaluation of data, and contributed to reports contained in this document.

G. Katnik	NASA - KSC	Shuttle Ice/Debris Systems
R. Speece	NASA - KSC	Thermal Protection Systems
R. Stevens	NASA - KSC	SRB Mechanical Systems
J. Rivera	NASA - KSC	ET Mechanisms/Structures
W. Boyter	NASA - KSC	SRB Mechanical Systems
R. Page	NASA - KSC	SSP Integration
K. Revay	USA - SFOC	Supervisor, ET/SRB Mechanical Systems
J. Blue	USA - SFOC	ET Mechanical Systems
W. Richards	USA - SFOC	ET Mechanical Systems
M. Wollam	USA - SFOC	ET Mechanical Systems
T. Ford	USA - SFOC	ET Mechanical Systems
R. Seale	USA - SFOC	ET Mechanical Systems
R. Brewer	USA - SFOC	ET Mechanical Systems
R. Oyer	Boeing	Systems Integration
C. Hill	Boeing	Systems Integration
D. Leggett	Boeing	Systems Integration
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J. Ramirez	LMMSS	ET Processing

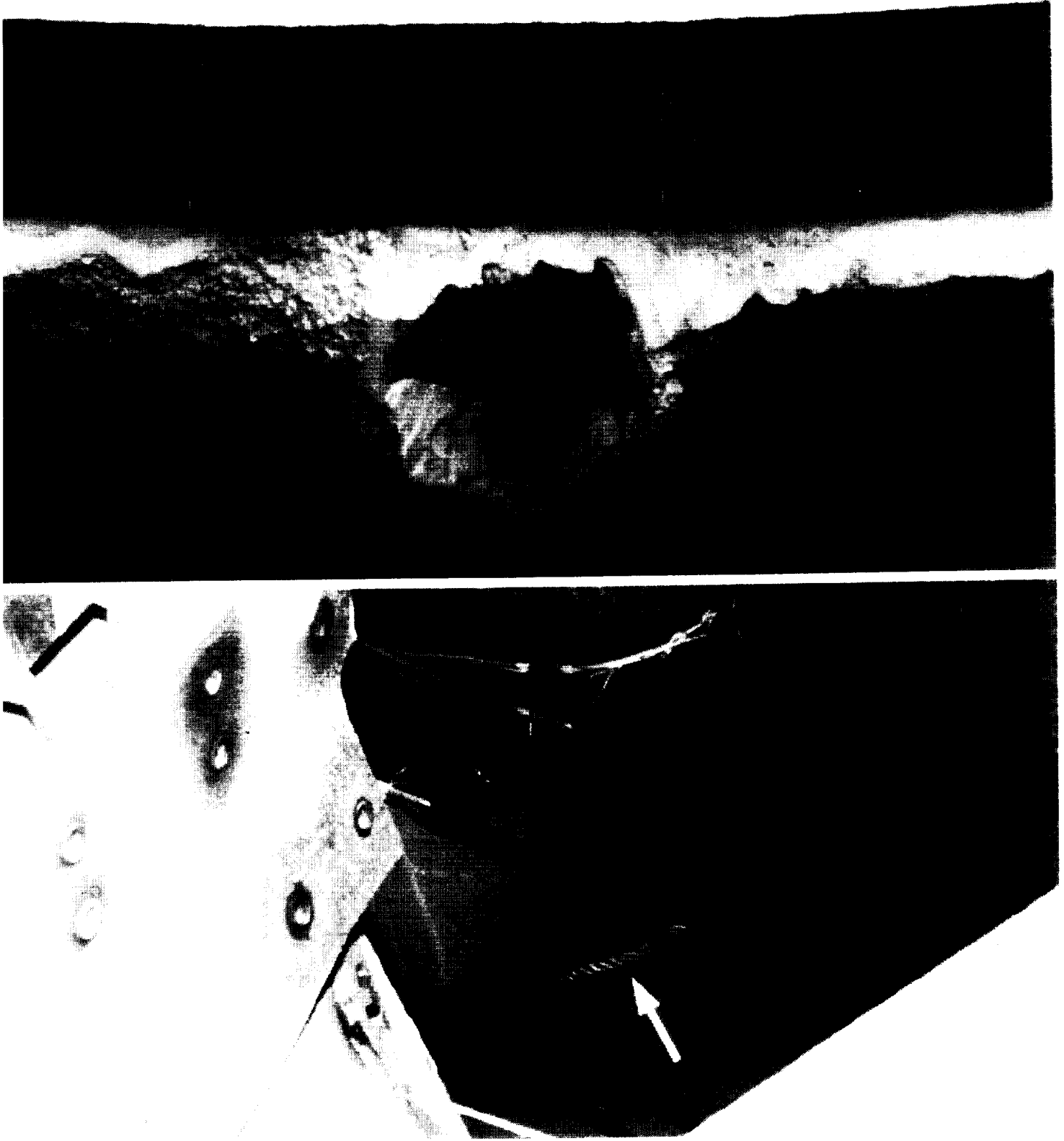
GSE PR V070-4-21-0387 was taken by NASA Quality to inspect the left wing lower surface for possible debris impact damage. During crane lift operations, a 5/16-inch bolt sheared in half and fell.

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 23 April 2000. The walkdown of Pad 39A and MLP-1 included the flight elements OV-104 Atlantis (19<sup>th</sup> flight), ET-102, and BI-101 SRB's. IPR 101V-0299 was taken to document four small areas of missing topcoat near the ET nose cone with disposition for MRB use-as-is. There were no significant SSV discrepancies though six items were entered in OMI S0007, Appendix K.

- Flange nut and lock washer missing on the center-north rainbird
- Loose/raised bolts in two locations on the MLP deck
- Loose foam in SRB APU exhaust pipe cut-outs
- Sand/debris in HDP #2 and #6 haunch areas
- Rope with metal thimble wrapped around water pipe in HDP #2 haunch area
- Loose items "out-of-reach" on MLP deck

The T-8 Hour Walkdown prior to clearing the BDA verified all items had been resolved.





**Photo 2: Pre-Launch Debris Inspection**

Loose foam pieces in RH SRB APU exhaust pipe cut-outs and a rope with a metal thimble wrapped around the water pipe in the HDP #2 haunch area were removed prior to tanking



### **3.0 SCRUBS**

#### **3.1 FINAL INSPECTION – WEATHER SCRUB 1**

A Final Inspection of the cryoloaded vehicle was performed on 24 April 2000 from 1020 to 1150 hours during the two-hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations relating to the flight hardware.

Due to the time of year, there were no acreage or protuberance icing concerns. All acreage was dry with virtually no condensate present. The ET LO2 tank acreage temperatures averaged 65 degrees F at the time of the inspection. The surface temperatures on the LH2 tank averaged 66 degrees F. There was no protuberance icing outside of the established database.

A total of six hairline cracks were detected in ET intertank valley TPS. There was one crack in each quadrant with the exception of the +Y+Z quadrant, which had three cracks. The cracks ranged in length from 4 to 18 inches, were less than 1/8-inch wide, had no offset, and exhibited no ice or frost. Therefore, all were acceptable for flight per NSTS-08303.

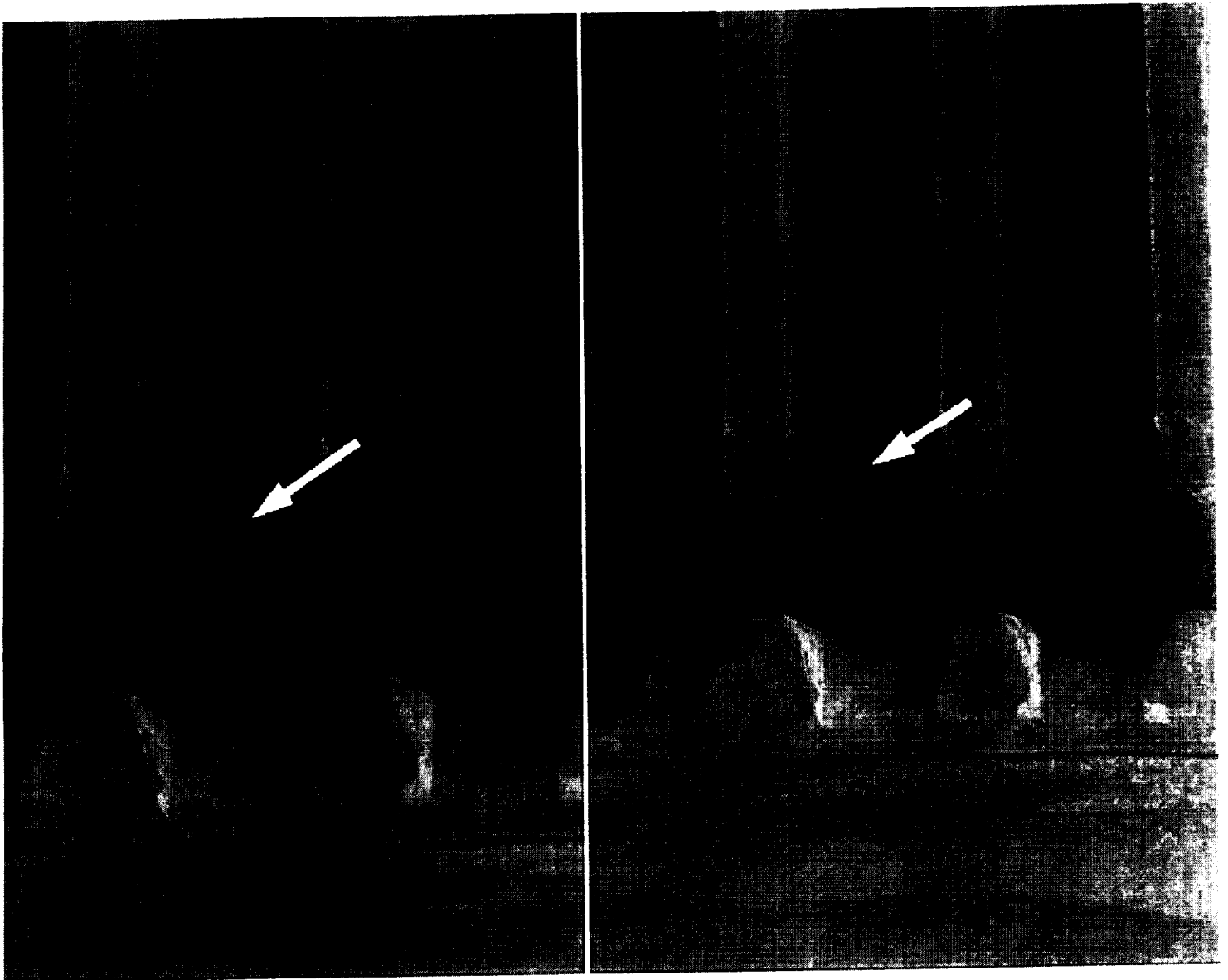
The -Y vertical strut exhibited a dogleg stress relief crack approximately 5 inches long by 1/8-inches wide, which was acceptable for flight per NSTS-08303.

There were no tile or RCC panel anomalies on the Orbiter. All RCS thrust paper covers were intact. The F2U and F3L covers were discolored, but not wet. Less than usual amounts of ice and frost had formed on the SSME nozzle to heat shield interfaces.

Launch was scrubbed at the end of the window due to weather violations (RTLS crosswinds).







**Photo 3: Hairline Cracks in Intertank Stringer Valleys**

A total of six hairline cracks were detected in ET intertank valley TPS. There was one crack in each quadrant with the exception of the +Y+Z quadrant, which had three cracks. The cracks ranged in length from 4 to 18 inches, were less than 1/8-inch wide, had no offset, and exhibited no ice or frost. Therefore, all were acceptable for flight per NSTS-08303.



### 3.2 POST DRAIN INSPECTION

The post drain inspection was conducted on 24 April 2000 from 2120 to 2230 hours under dark conditions. Prior to leaving LCC Firing Room 2, a request was made to have the xenon lights turned on. The inspection was performed with adequate lighting.

The southwest (-Y) ET GOX vent seal footprint area was in clear view from the end of the GOX vent arm. An inspection of the footprint area revealed no new topcoat damage areas. The visible areas of missing topcoat compared exactly to those documented on IPR 101V-0299. The northeast (+Y) ET GOX vent seal footprint area was not accessible for inspection with the GOX vent hood lifted. OTV surveillance inspection during detank operations of seal deflation and hood lift revealed no indications of topcoat peel-off or adhesion of the seal to the ET footprint. OTV inspection of the seals showed no indication of topcoat adhering to the seal material.

The External Tank was in excellent condition. Bipod jack pad standoff closeouts were nominal. All PDL repairs were intact with none protruding. No crushed foam or debris was detected in the LO2 feedline support brackets. The stress relief crack in the -Y vertical strut forward surface TPS was not visible. A small frost spot was present on the LH2 aft dome apex closeout. Vapors had been observed from the firing room OTV in this area lasting approximately two minutes.

The only ice/frost accumulations remaining were located in the LO2 feedline bellows and support brackets, the LH2 ET/ORB umbilical purge curtain barrier, and on the ET/ORB umbilical purge vents.

Orbiter tiles, RCC panels, and SSME's were in nominal configuration. RCS thruster paper covers were intact, though the cover on R4R was discolored.

The MLP deck inspection revealed tape at the sound suppression down-comer pipe support adjacent to HDP #2.

In summary, the drain inspection produced no IPR conditions and no flight hardware concerns. There were no constraints for the next cryoload.

### 3.3 FINAL INSPECTION – WEATHER SCRUB 2

A Final Inspection of the cryoloaded vehicle was performed on 25 April 2000 from 1000 to 1130 hours during the two-hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations relating to the flight hardware.

Due to the time of year, there were no acreage or protuberance icing concerns. All acreage was mostly dry with a small amount of condensate present. The ET LO2 tank acreage temperatures averaged 68 degrees F at the time of the inspection. The surface temperatures on the LH2 tank averaged 66 degrees F. There was no protuberance icing outside of the established database.

Generally, the ET was in excellent condition for a second cryogenic loading.

The number of cracks detected in ET intertank valley TPS increased from 6 to 12. There were cracks in all four quadrants. The cracks ranged in length from 2 to 18 inches, were less than 3/16-inch wide, had no offset, and exhibited no ice or frost. Therefore, all were acceptable for flight per NSTS-08303.

The -Y vertical strut exhibited a dogleg stress relief crack approximately 5 inches long by 1/8-inches wide, which was acceptable for flight per NSTS-08303.

A thermal short created an ice formation 4-inches long by 1-inch wide by 3/8-inch thick on the +Y longeron. No crack in the TPS was visible during this observation. The condition was acceptable for flight per NSTS-08303.

There were no tile or RCC panel anomalies on the Orbiter. All RCS thrust paper covers were intact. The F2U and F3L covers were discolored and slightly wetter. Four additional covers (F1D, F3U, R1R, R4R) were slightly discolored. Typical amounts of ice and frost had formed on the SSME nozzle to heat shield interfaces.

Launch was scrubbed at the end of the window due to weather violations (high winds).

### 3.4 POST DRAIN INSPECTION

The post drain inspection was conducted on 25 April 2000 from 1900 to 2030 hours under sunset conditions. Prior to leaving LCC Firing room 2, a request was made to have the xenon lights turned on. The inspection was performed with adequate lighting.

The southwest (-Y) ET GOX vent seal footprint area was in clear view from the end of the GOX vent arm. An inspection of the footprint area revealed no new topcoat damage areas. The visible areas of missing topcoat compared exactly to those documented on IPR 101V-0299. The northeast (+Y) ET GOX vent seal footprint area was not accessible for inspection with the GOX vent hood lifted. OTV surveillance inspection during detank operations of seal deflation and hood lift revealed no indications of topcoat peel-off or adhesion of the northeast seal to the footprint. Technician inspection of the seals confirmed no topcoat adhering to the seal material.

The External Tank was in excellent condition. Bipod jack pad standoff closeouts were nominal. The twelve cracks observed in Intertank stringer valleys during final inspection were no longer visible. All PDL repairs were intact with none protruding. No crushed foam or debris was detected in the LO2 feedline support brackets. The stress relief crack in the -Y vertical strut forward surface TPS was not visible. A four-inch crescent shaped crack was detected in the +Y longeron closeout at approximate station XT-1960 and documented on IPR 101V-0310. Preliminary approval for MRB use-as-is had been coordinated with LMMSS-MAF pending only final dimensions that would be obtained during the next Final Inspection at T-3 hours.

Ice/frost accumulations were still present at the ET/SRB cable tray to aft fairing interface, the LO2 feedline bellows and support brackets, the LH2 ET/ORB umbilical purge curtain barrier, LH2 recirculation line bellows, and on the ET/ORB umbilical purge vents.

Orbiter tiles, RCC panels, and SSME's were in nominal configuration. RCS thruster paper covers were intact, though the R1R and R4R covers were discolored.

In summary, the drain inspection produced no IPR conditions and concerns with flight hardware. There were no constraints for the next cryoload.

### 3.5 FINAL INSPECTION - WEATHER SCRUB 3

A Final Inspection of the cryoloaded vehicle was performed on 26 April 2000 from 1015 to 1110 hours during the two-hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations relating to the flight hardware. IPR 101V-0310 was taken for two cracks in the +Y longeron.

Due to the time of year, there were no acreage or protuberance icing concerns. The ET LO2 tank acreage temperatures averaged 54 degrees F at the time of the inspection. The surface temperatures on the LH2 tank averaged 56 degrees F. There was no protuberance icing outside of the established database.

Generally, the ET was in excellent condition for a third cryogenic loading. As expected, there were a greater number of small thermal shorts, made visible by frost accumulations, in various places.

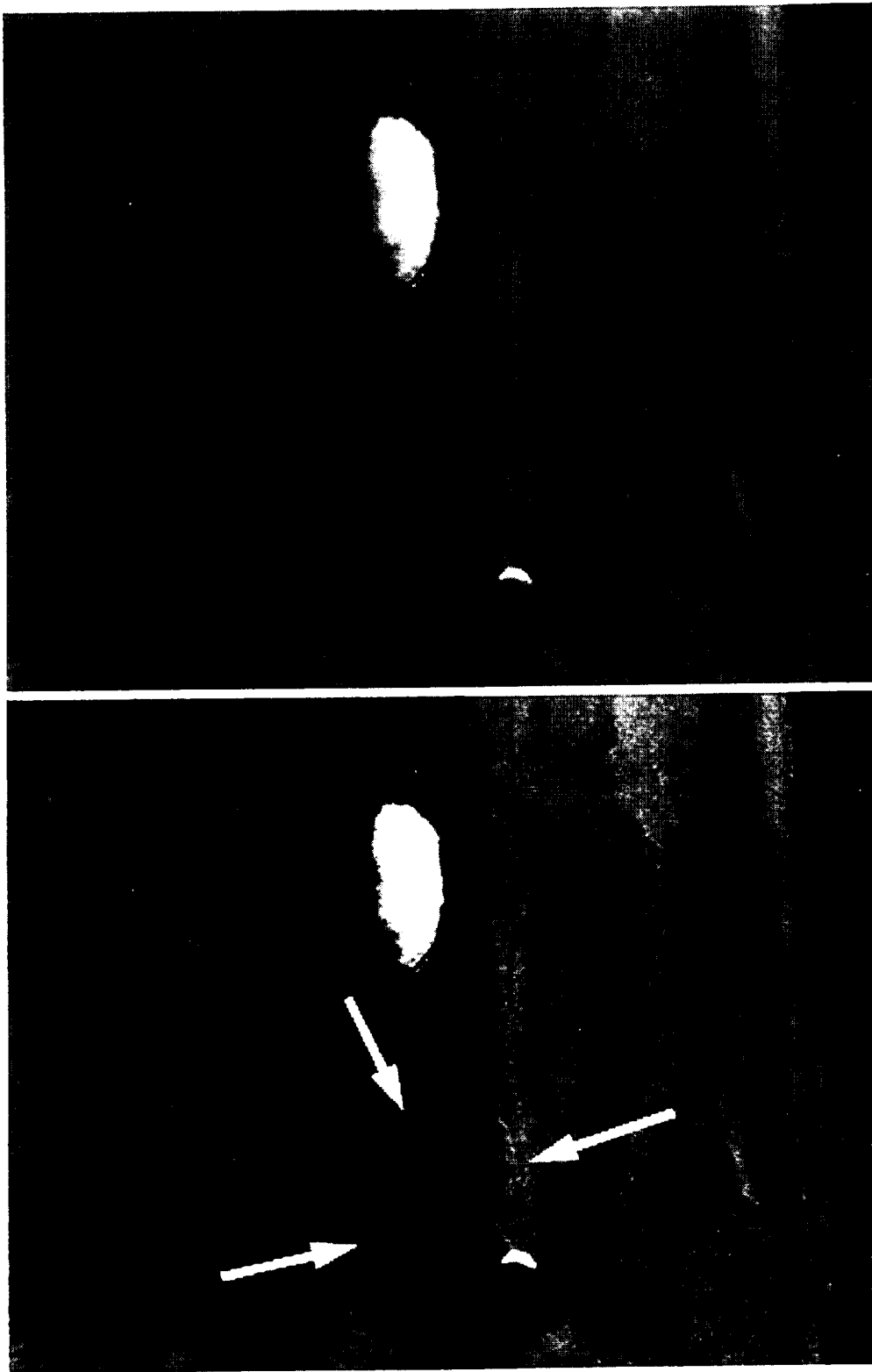
The number of cracks detected in ET intertank valley TPS increased from 12 to 14. There were cracks in all four quadrants. The cracks ranged in length from 2 to 18 inches, were less than 3/16-inch wide, had no offset, and exhibited no ice or frost. Therefore, all were acceptable for flight per NSTS-08303

The 5-inch dogleg stress relief crack in the -Y vertical strut TPS was joined by a separate 3-inch long crack. This condition has been accepted for flight on previous vehicles.

IPR 101V-0310 was taken for two cracks in the +Y longeron closeout TPS since this condition was outside the NSTS-08303 guidelines. One crack was 4 inches in length by 3 inches wide by 1/8-inch wide in an inverted horseshoe shape. The second crack was horizontal, 2-inches long, and hairline in width. Although some frost was present, neither exhibited any offset nor unusual temperature gradients as imaged by the infrared radiometer. The two cracks were caused by thermal/mechanical induced stresses and localized defects in the thick BX-250 TPS closeout. In the case of the larger crack, a more severe condition occurred during the second cryoload of STS-99 (reference IPR 099V-0193). That condition was approved for flight via MRB on PR ET-92-TS-0010 and the same rationale, essentially, was used for the condition on this vehicle.

There were no tile or RCC panel anomalies on the Orbiter. All RCS thrust paper covers were intact though the F1D, F2U, F3U, F3L, R1R, and R4R were discolored and wet. Typical amounts of ice and frost had formed on the SSME nozzle to heat shield interfaces.

Launch was scrubbed at the end of the window due to weather violations (high winds).



**Photo 4: Crack in +Y Longeron TPS**

Normal and enhanced views of inverted horseshoe-shaped crack in the +Y longeron TPS





### 3.6 POST DRAIN INSPECTION

The post drain inspection was conducted on 26 April 2000 from 2010 to 2130 hours under sunset conditions. Prior to leaving LCC Firing room 2, a request was made to have the xenon lights turned on, this request was not fulfilled as the xenon light generators needed refueling. The inspection was performed with adequate available lighting.

The External Tank was in excellent condition. The fourteen cracks in the intertank stringer valleys were no longer visible. Bipod jack pad standoff closeouts were nominal. All PDL repairs were intact with none protruding. No crushed foam or debris was detected in the LO2 feedline support brackets. The two small stress relief cracks in the -Y vertical strut forward surface TPS were not visible.

The crescent shaped crack at station XT-1960 previously documented on IPR 101V-0310 and MRB PR-ET-102-TS-0012 was carefully inspected. The crack was approximately 3-inches by 4-inches horseshoe shaped with an apparent 1/8-inch offset based on shadows cast on the adjacent foam. The ends of the crack were separated by approximately 4 inches of undamaged foam.

A second hairline crack on the +Y longeron closeout foam previously documented during the Final Inspection increased from 2 to 4 inches in length without offset. It remained a singular crack with no evidence of branching.

The -Y GOX vent footprint area had not changed since last inspection. The four areas of missing topcoat had not increased in size and no damage was noted. An inspection of the GOX vent seals revealed no indications of ET topcoat adhesion.

Small amounts of ice/frost accumulations were present at the ET/ORB LO2 and LH2 umbilicals and in the LO2/LH2 feedline bellows.

A small amount of froth and condensate was noted on the aft dome apex along with a small area of frost on the siphon access closeout at the +Y side. No TPS cracks were visible on the LH2 aft dome.

Orbiter tiles, RCC panels, and SSME's were in nominal configuration. RCS thruster paper covers were intact, though the R1R and R4R covers were discolored.

In summary, no new flight hardware concerns were detected during the post drain inspection that presented a constraint for the next launch attempt.

## **4.0 LAUNCH**

### **4.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION**

Due to the long interval between launch attempts, the cracks in the +Y longeron closeout TPS were re-assessed. PR ET-102-TS-0012 documented the location and size of the cracks, which were accepted by MRB use-as-is for flight. The condition of the cracks during any subsequent cryoloadings would be compared to this baseline.

Superficial foam damage on the LO2 feedline attach brackets at ET stations XT-1129, -1377, and -1623 were documented on PR ET-102-TS-0013, -0014, and -0015 with MRB approval to fly-as-is.

A second pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 18 May 2000. The only discrepancy noted was a black string, possibly part of a fabric tether, on the ET crossbeam. No action was recommended with the expectation the high winds at the pad would blow the tether off the flight hardware before liftoff.

Some time later, another debris concern involved the detection of a small braided tether cable (metal) resting on the ET crossbeam +Z side. The tether was estimated to be 5-6 inches in length, 1/16 to 1/8 inches in diameter, and a mass of 2 grams. The tether most likely fell from the upper levels of the RSS during platform securing operations prior to RSS rollback. Since the OWP's had been retracted already, no action to remove the tether was recommended based on the tether's minimal debris threat to the flight hardware. IPR 101V-0331 was taken with disposition showing the aft location at XT-2048 was no worse than high density ice from the ET/ORB umbilicals near this location, and initial flight aerodynamic cross flow would push the tether outboard away from Orbiter tiles. As a worst case scenario with the tether moving toward tiles, there would be an insignificant aerodynamic acceleration due to the low cross-sectional frontal area resulting in little or no damage. MRB approved the condition to use as-is.

### **4.2 FINAL INSPECTION**

The Final Inspection of the cryoloaded vehicle was performed on 19 May 2000 from 0015 to 0145 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC) or OMRS criteria violations. There were no acreage icing concerns. There were also no protuberance icing conditions outside of the established database.

A portable Shuttle Thermal Imager (STI) infrared scanning radiometer was utilized to obtain vehicle surface temperature measurements for an overall thermal assessment of the vehicle, particularly those areas not visible from remote fixed scanners, and to scan for unusual temperature gradients.

#### **4.2.1 ORBITER**

No Orbiter tile or RCC panel anomalies were observed. The RCS thruster paper covers were intact but four covers (F2U, F3L, F4D, R1R) were discolored. Ice/frost had formed on the SSME #1 and #2 heat shield-to-nozzle interfaces. The SSME #3 heat shield was dry.

#### **4.2.2 SOLID ROCKET BOOSTERS**

SRB case temperatures measured by the STI radiometers were close to ambient temperatures. All measured temperatures were above the 34 degrees F minimum requirement. The predicted Propellant Mean Bulk Temperature supplied by THIO was 73 degrees F, which was within the required range of 44-86 degrees F.

### 4.2.3 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run as a comparison to infrared scanner point measurements.

During this fourth cryogenic loading, the Final Inspection Team observed light condensate on the LO2 tank acreage. Surface temperatures averaged 57 degrees F. There were no TPS anomalies.

No significant anomalies were present in the intertank TPS. The 14 stringer valley TPS cracks detected during the previous cryoloads had increased to a total of 15 with the appearance of an additional hairline crack in the -Y-Z quadrant. Ice and frost accumulations on the GUCP were typical.

Light condensate was present on the LH2 tank acreage. Surface temperatures ranged from 58 to 66 degrees Fahrenheit. There were no acreage TPS anomalies.

Typical amounts of ice/frost had accumulated in the LO2 feedline bellows and support brackets. Also as expected for a fourth cryoload, there were numerous small frost spots on various closeout bondlines including two places on the -Y bipod housing closeout bondline.

The 5-inch dogleg stress relief crack in the -Y vertical strut TPS and separate 3-inch long crack had not changed significantly since the last cryoload. This condition has been accepted for flight on previous vehicles.

The cracks and ice/frost accumulations in the +Y longeron closeout TPS as documented prior to tanking had not changed. Therefore, no new IPR was required.

There were no TPS anomalies on the LO2 ET/ORB umbilical. Ice/frost accumulations were present on the aft and inboard sides. Ice/frost fingers on the separation bolt pyrotechnic canister purge vents were typical.

Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. Likewise, a typical amount of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier outboard side, forward, and aft surfaces. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

Overall, the ET was in excellent condition for a fourth cryogenic loading with no significant changes from the previous tanking.

### 4.2.4 FACILITY

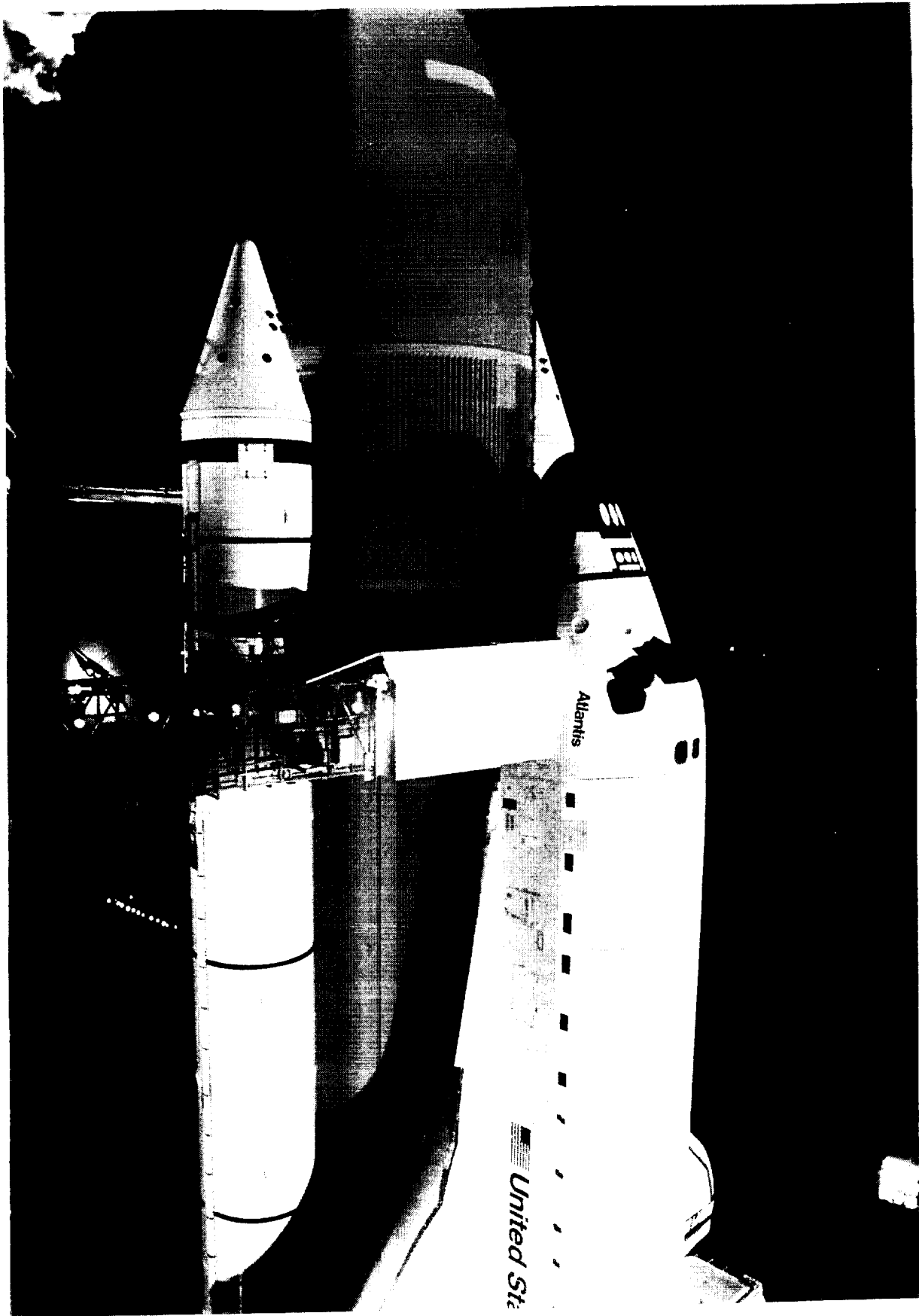
All SRB sound suppression water troughs were filled and properly configured for launch. No leaks were observed on the GUCP or the LO2 and LH2 Orbiter T-0 umbilicals.

### 4.3 T-3 HOURS TO LAUNCH

After completion of the Final Inspection on the pad, surveillance continued from the Launch Control Center. Twenty-two remote-controlled television cameras and two infrared radiometers were utilized to perform scans of the vehicle. No ice or frost on the acreage TPS was detected. Protuberance icing previously assessed did not increase. At T-2:30, the GOX vent seals were deflated and the GOX vent hood lifted. Although frost covered some of the ET nose cone louvers - an expected condition - no ice was detected. When the heated purge was removed by retraction of the GOX vent hood, frost continued to form on the louvers until liftoff. At the time of launch, there were no ice accumulations in the "no ice zone".

STS-101 was launched at 140:10:11:09.994 UTC (6:11 a.m. local) on 19 May 2000.





**Photo 5: ET LO2 Tank and Intertank**

During this fourth cryoload, the External Tank was in excellent condition. The Final Inspection Team observed light condensate on the LO2 tank acreage. Surface temperatures averaged 57 degrees Fahrenheit. No TPS anomalies were detected.



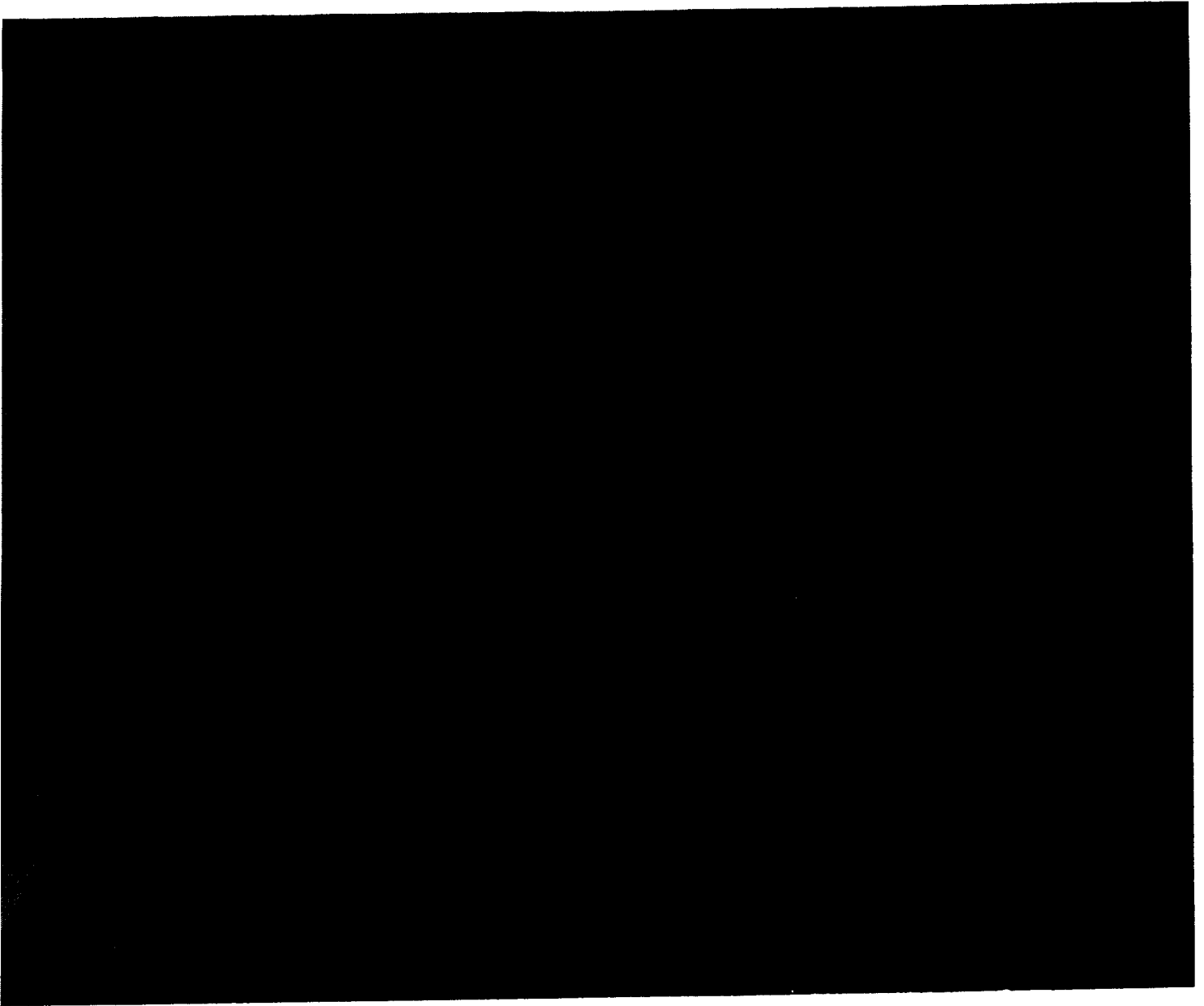


**Photo 6: LH2 Tank Acreage**

Light condensate was present on the LH2 tank acreage. Surface temperatures ranged from 58 to 66 degrees Fahrenheit. There were no acreage TPS anomalies.







**Photo 7: Cracks in Intertank Stringer Valleys**

No significant anomalies were present in the intertank TPS. The 14 stringer valley TPS cracks detected during the previous cryoloads had increased to a total of 15 with the appearance of an additional hairline crack in the -Y-Z quadrant.

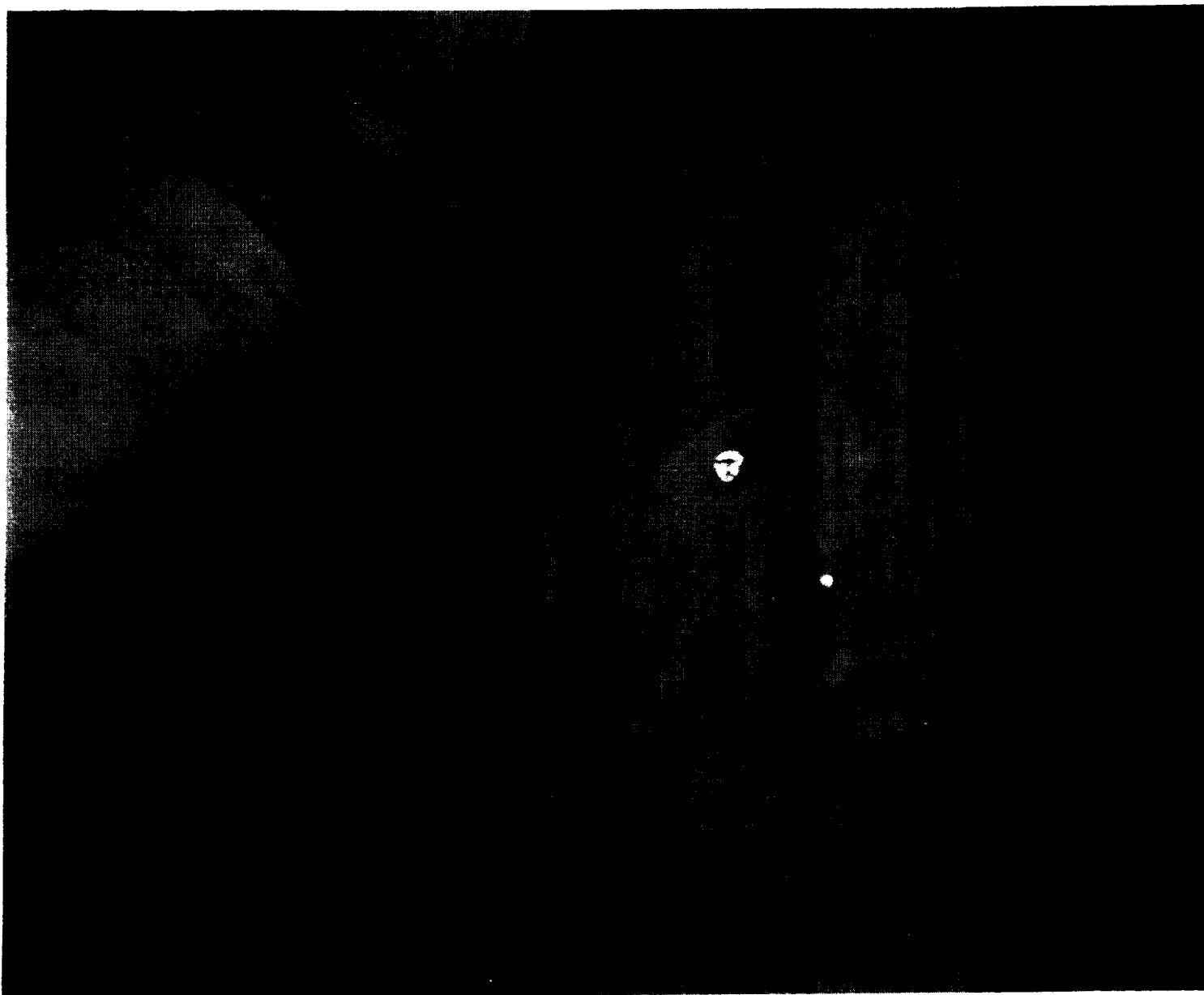




**Photo 8: ET +Y Longeron**

As typically happens during multiple cryogenic loadings, randomly scattered thermal shorts produced small ice/frost formations as seen here in the +Y longeron closeout foam





**Photo 9: ET +Y Longeron TPS**

The cracks and ice/frost accumulations in the +Y longeron closeout TPS documented prior to tanking had not changed. Therefore, no new IPR was required.



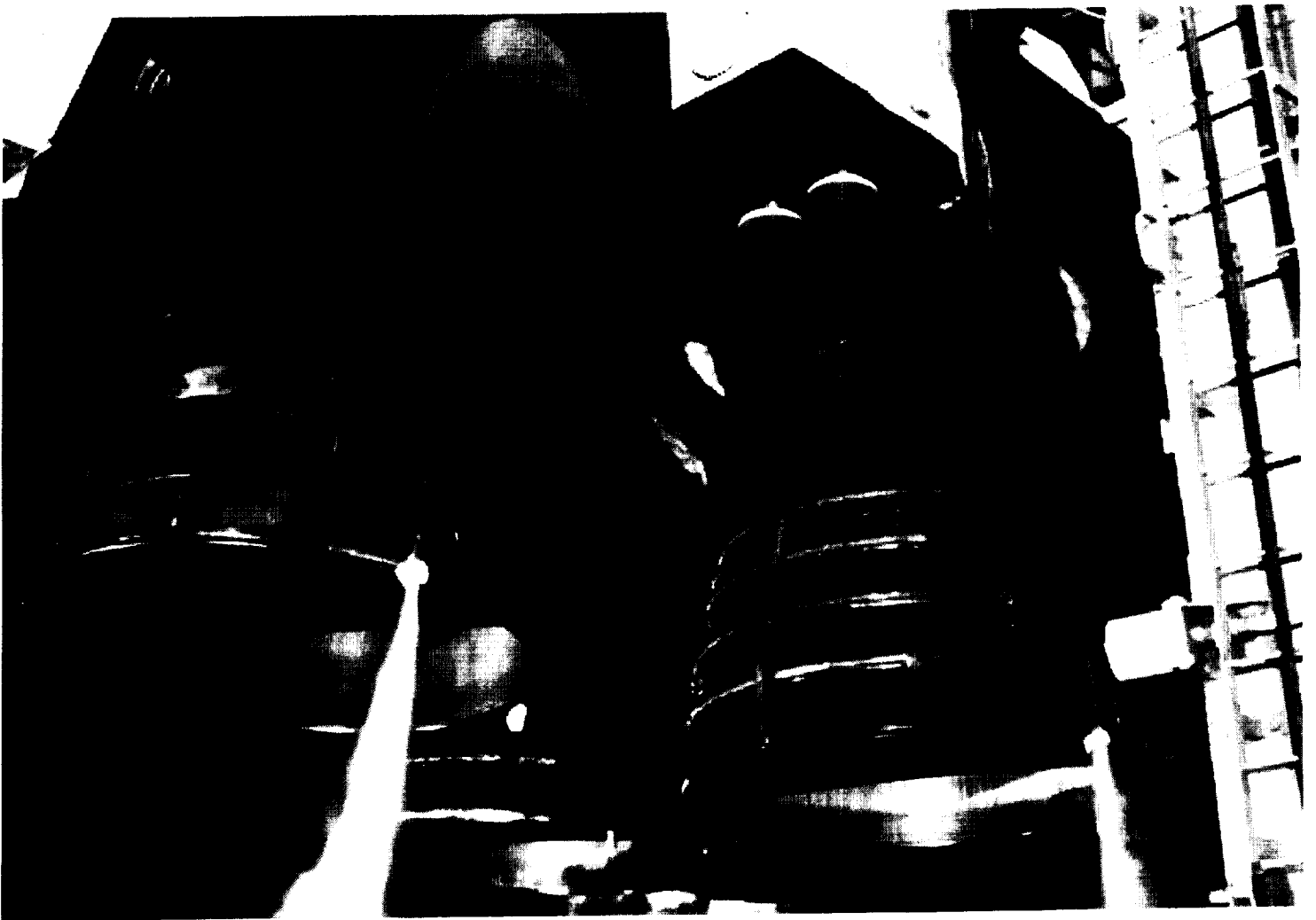


Photo 10: Overall View of SSME's





## 5.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of the MLP, Pad A FSS and RSS was conducted on 19 May 2000 from Launch + 2 to 4 hours. No flight hardware was found.

A stud hang-up was not expected on this launch. Boeing-HB reported an Orbiter liftoff lateral acceleration of 0.09 g's which is below the threshold (0.14g's) for stud hang-ups. Erosion was typical for the south posts. North holddown post blast covers and T-0 umbilicals exhibited typical exhaust plume damage. The blast cover for HDP #8 was modified with an ablative test coating material to protect the steel cover from SRB plume erosion. The material ablated as designed with no apparent damage to the metal cover. Both SRB aft skirt GN2 purge lines were intact, though the protective tape was almost entirely eroded away with minimal damage to the underlying braided shield.

The LO2 and LH2 Tail Service Masts (TSM) appeared undamaged and the bonnets were closed properly. The Orbiter Access Arm (OAA) seemed to be undamaged.

The MLP deck was in generally good shape with one missing bolt from a deck access panel on the southwest side. The panel is adjacent to the one previously noted on the L-20 hour inspection as not having peripheral RTV sealant applied.

The GH2 vent line latched in the eighth of eight teeth of the latching mechanism. The GUCP 7-inch QD sealing surface exhibited no damage. Pieces of the T-0 lock weight guide roller assemblies were found on the adjacent deck grating and pad surface.

The GOX vent arm, hood, ducts and structure appeared to be in good shape with no indications of plume damage. The vent seals were inspected for ET topcoat adherence. Several small spots of topcoat were observed on the +Y seal lower surface. No topcoat was observed on the -Y seal.

Debris findings on the FSS included loose or missing cable tray and conduit covers, and loose electrical cables and broken lighting fixtures, which are typically found. The 235-foot level FSS sign was loose and missing hardware.

No significant damage occurred in the flame trenches. No flight debris was found in the Pad acreage.

The FSS or PCR panel observed during Launch Day Video Review was not found during this inspection. Overall, damage to the pad appeared to be minimal.

An underground gas line, media unknown, was observed venting through the ground. This was observed emanating from the remote ECS tunnel adjacent to LOX cable tray on the west side of the PTCR. Pad leader was advised for immediate action.

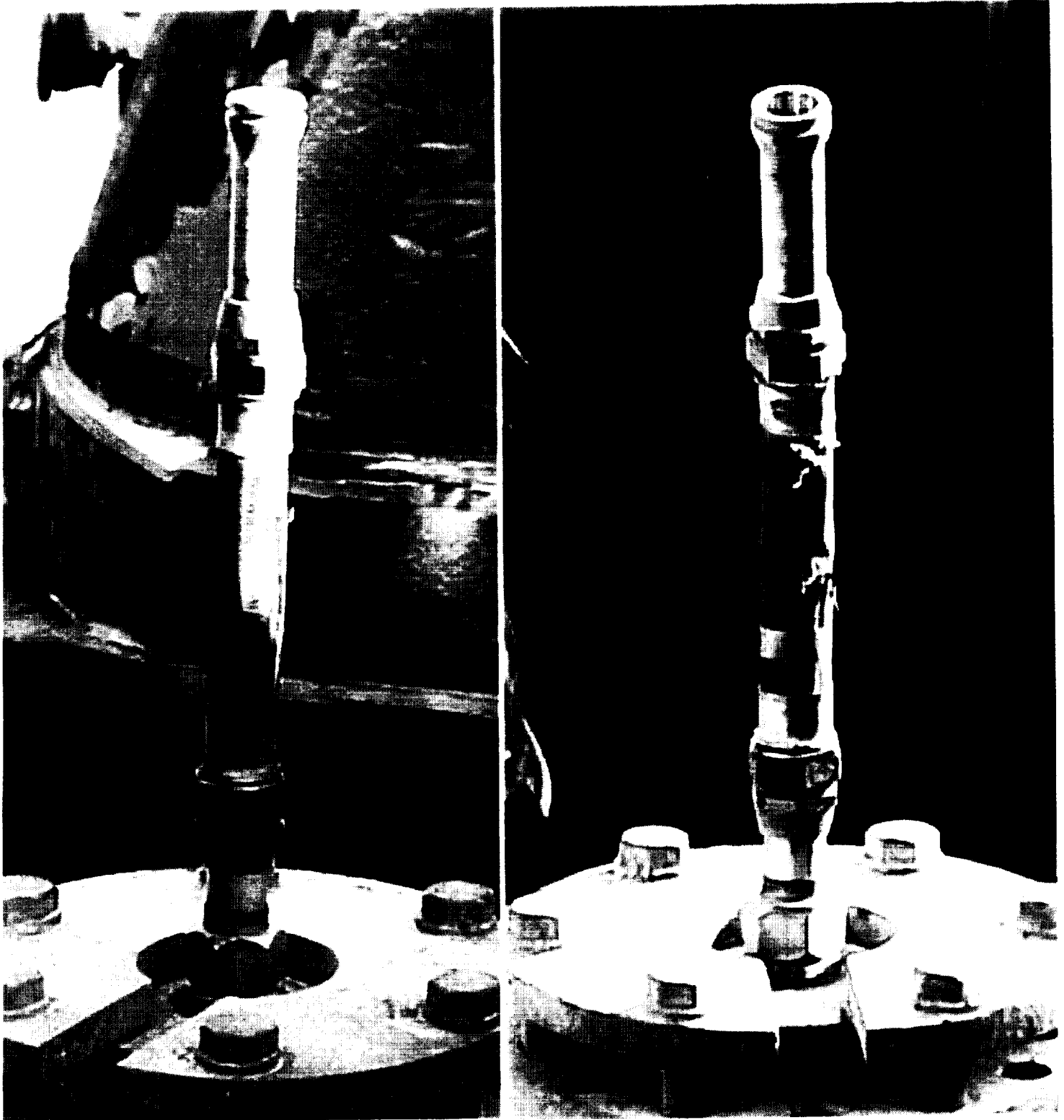




**Photo 11: HDP #8 Blast Cover Coating**

The blast cover for HDP #8 was modified with an ablative test coating material to protect the steel cover from SRB plume erosion. The material ablated as designed with no apparent damage to the steel cover.





**Photo 12: Aft Skirt GN2 Purge Lines**

Both SRB aft skirt GN2 purge lines were intact, though the protective tape was almost entirely eroded away with minimal damage to the underlying braided shield.



## 6.0 FILM REVIEW

Anomalies observed in the Film Review were reported to the Mission Management Team, Shuttle managers, and vehicle systems engineers. No IPR's or IFA's were generated as a result of the film review.

### 6.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 84 films and videos, which included twenty-eight 16mm films, eighteen 35mm films, and thirty-eight videos, were reviewed starting on launch day.

Frost, but no ice, formed on the ET louvers after GOX vent seal retraction (OTV 060).

SSME ignition appeared normal with Mach diamonds forming in the expected 3-2-1 sequence. Two streaks occurred in the SSME exhaust plume from early liftoff through tower clear (E-2, -3, -19, -20, -52, -76, -77; OTV 051, 070, 071).

Free burning hydrogen was visible in the orbiter base heat shield area, near the drag chute door, vertical stabilizer root, and under the body flap during SSME ignition (OTV 063, 070, 071, TV-7).

SSME ignition caused numerous pieces of ice from the LH2 ET/ORB umbilical to fall aft. Some pieces impacted the umbilical cavity sill, but no tile damage was visible. In addition, a piece of 1-inch wide mylar tape came loose from the forward portion of the ET/ORB LH2 umbilical purge barrier and fell aft (OTV 009, 054).

Small pieces of tile surface coating material were lost during ignition from several places on the base heat shield outboard of SSME #3 and SSME #2, on the +Y APCS pod aft surface, and on the body flap +Z side outboard of SSME #3 (OTV 070; E-17, -18, -19, -20).

Retraction of the LO2 Orbiter T-0 carrier plate caused pieces of ice to shake loose and fall aft impacting the SSME #3 nozzle near the #8 hatband. No damage occurred (OTV 070).

Although not an anomaly but just an unusual occurrence, a total of seven aft RCS thruster paper covers were still intact after T-0 as the vehicle lifted off. The covers normally are torn by SSME ignition vibration and acoustics early in the start-up process (OTV 049, 050).

Several pieces of ice/frost that had formed on the +Y longeron during tanking as a result of the cracks in the closeout TPS fell aft and impacted the +Y vertical strut. These impacts did not cause any damage (OTV 054).

GUCP disconnect from the ET was normal. There was no TPS damage (E-33).

No holddown post stud hang-ups occurred on this launch. No debris fell from the DCS stud holes (E7-14). IFA STS-101-1-01 was taken for unusual high frequency responses in the strain gage data on holddown posts M-2 and M-4. However, film review showed no unusual vehicle or GSE movements/anomalies in these areas.

The GN2 purge lines separated cleanly from both SRB aft skirts at liftoff. The purge lines were visible for about two seconds after T-0. No anomalies were observed (E-8, -13).

Several pieces of SRB throat plug were ejected from the flame trench after T-0 in northern trajectories away from the SSV (TV-7). A long, thin, dark debris object, most likely a piece of SRB throat plug or sound suppression water trough material, crossed the field of view moving northward away from the vehicle at 11:11.623 GMT (E-1, -41).

TV-21 showed an object believed to be a cable tray cover from the FSS or a PCR panel from the RSS moving westward away from the SSV shortly after T-0. The object appeared to originate from the 135 or 155 foot level of those structures.

All views showing the +Y longeron containing the cracked TPS detected prior to launch confirmed no foam loss while in the field of view. The 2-inch diameter ice/frost formation was still attached to the +Y longeron at the start of the roll maneuver (E-52, -54).

Condensate drained from the split rudder/speed brake shortly after liftoff (E-52).

TV-4A recorded pieces of forward RCS thruster paper covers falling aft of the vehicle at 16.5 and 27 seconds MET. A large flare occurred in the SSME #1 exhaust plume at 53 seconds MET for 0.17 seconds duration in this field of view. This type of flare is usually caused by debris, such as a particle of SRB aft skirt aft ring instafoam, passing through the exhaust plume. The large flare in the SSME #1 exhaust plume at 10:12:03.279 GMT was also visible in E-207 frame 2804, E-220 frame 5803, E-222, -223, and -224.

At least two more pieces of instafoam fell aft at 64 and 74 seconds MET.

A circumferential ring, somewhat brighter than the adjacent hot wall nozzle material but not an anomaly, was visible in SSME #2 (E-207).

Frequency and amplitude of body flap motion appeared to be typical. The view from film item E-207 was especially good.

SRB tail-off and separation appeared normal. Numerous pieces of slag falling out of the exhaust plume during and after SRB separation was typical (TV-4, TV-13).

OMS engine ignition was easily visible in film items E-208 and 212.

### **6.1.1 Vaporous Streak at 34 Seconds MET**

An impact occurred at 10:11:44.109 GMT (approx. T+34 seconds MET) on the Orbiter lower surface at a point that appeared to be about 8 feet forward of the right inboard elevon hinge, perhaps centered with respect to the elevon or just a little more outboard (E-224).

This event in turn caused a light-colored, "vaporous" streak to pass the trailing edge of the right inboard elevon at T+34 seconds MET.

The debris object was white, or light-colored, perhaps 6 inches in length, and disintegrated upon impact thereby comprising most of the material in the "streak", though there may also have been some tile material as well from the damage site.

After the impact, no damage site could be discerned. However, the film was grainy and individual tiles could be resolved. Therefore, the damage site was not extremely large, which would have been visible to some degree.



The debris object appeared to originate from the mid-body area of the vehicle, though that could not be precisely determined due to the grainy nature of the image as well as that portion of the vehicle being in deep shadow.

Since the debris object disintegrated upon impact with no large particles visible in the "streak", the object most likely was a piece of ET foam or crusty ice from the ET LO2 feedline bellows or support brackets. It is unlikely the object was a piece of SRB insulation since no significant material was found to be missing during the post flight inspection at Hangar AF. Likewise, the object could not be a white tile since the trajectory would take it aft over the wing with no mechanism to carry a white tile along the lower surface.

A second, very nebulous streak occurred approximately 7 second later (11:51.5 GMT). That may indicate either another piece of foam or ice came loose and followed the same trajectory, or the tile damage site continued to erode.

This streak was compared to a somewhat similar streak detected on STS-26R, which was the result of a debris impact that caused a tile damage site 18 inches long by 8 inches wide by 1.5 inches deep. However, the STS-101 streak was considerably less "dense" indicating a much smaller damage site.

Shuttle Program management elected not to use the RMS for a tile survey due to lighting problems and poor resolution on such previous surveys. However, it was prudent to take some precautions anyway, so the Orbiter performed a thermal conditioning maneuver prior to re-entry to cold bias the right wing and elevon structure. This increased the temperature margin and, therefore, reduced the potential for structural damage. The detection of the debris impact and resulting damage site was not considered a Safety of Flight issue, but more of an R&R effort after landing.

## **6.2 SRB CAMERA VIDEO SUMMARY**

Both cameras provided good views. Lighting and focus were excellent. The fields of view on this flight were compared to STS-103. The +Y side of STS-101 was identical to STS-103. The -Y side was shifted 1.5 inches in the +Z direction and 4 inches in the -X direction, which was an insignificant change.

As expected, divots were smaller in size and fewer in number in the vented areas of the thrust panels when compared to the unvented areas. Some very small areas of exposed "new" foam were caused by normal ascent recession/erosion and not included in the total divot count. Divots were very shallow with no primed substrate visible. Most divots were small and less than 0.5 inches in diameter.

There was a greater number of divots visible in the right field of view (+Y side) compared to the left (-Y) side.

The right SRB camera viewing the +Y side of the ET recorded a light colored spot appearing at 90 seconds MET on the Orbiter lower surface that may be a tile damage site. However, no debris object was observed impacting this area.

A divot approximately 9-inches in diameter was present on the ET -Z side at the intertank-to-LH2 tank interface.

### 6.2.1 -Y Side Divot Count

100 seconds MET	One small divot appeared in vented rib #18 just aft of Xt-963
100-110 sec MET	10 total divots on ribs (none greater than 1-inch in size)
110-120 sec MET	38 total divots (with 1 greater than 1-inch in size on rib #23)
120-124 sec MET	58 total divots (no additional divots greater than 1-inch)
After separation	3-inch divot at rib #15 adjacent to LH2 acreage flange closeout

### 6.2.2 +Y Side Divot Count

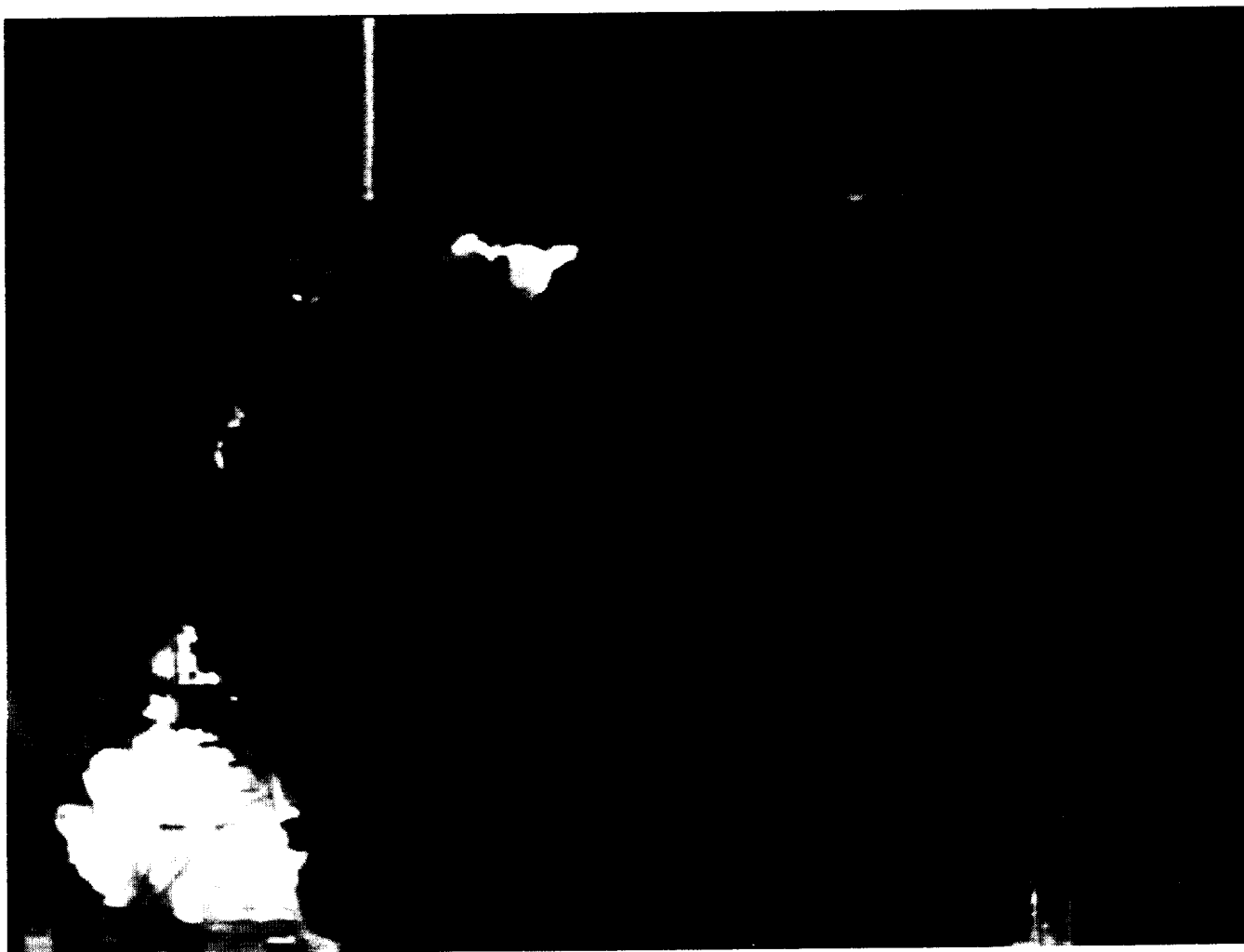
99 seconds MET	First divot appeared on the circumferential rib ramp at Xt-963 between ribs #5 and #6
99-109 sec MET	23 divots in the vented area (zero greater than 1-inch in size) 14 divots in unvented area aft of station Xt-1013 (with four greater than 1-inch)
109-119 sec MET	78 divots in the vented area (one greater than 1-inch rib #7) 50 divots in unvented area aft of station Xt-1013 (with 16 greater than 1-inch aft of Xt-1013 at ribs #2, #3, and #4)
119-124 sec MET	92 divots in the vented area (one greater than 1-inch rib #7) 78 divots in unvented area aft of station Xt-1013 (with 21 greater than 1-inch aft of Xt-1013 at ribs #2, #3, and #4)
After separation	Numerous large divots visible in the unvented area aft of Station Xt-1013 with the largest estimated 3-4 inches long  6 divots were noted in adjacent valley ramps of ribs #1-7 at circumferential rib station Xt-1058



**Photo 13: Ice Contacting SSME #3 Nozzle**

Retraction of the LO2 Orbiter T-0 carrier plate caused pieces of ice to shake loose and fall aft impacting the SSME #3 nozzle near the #8 hatband. No damage occurred.

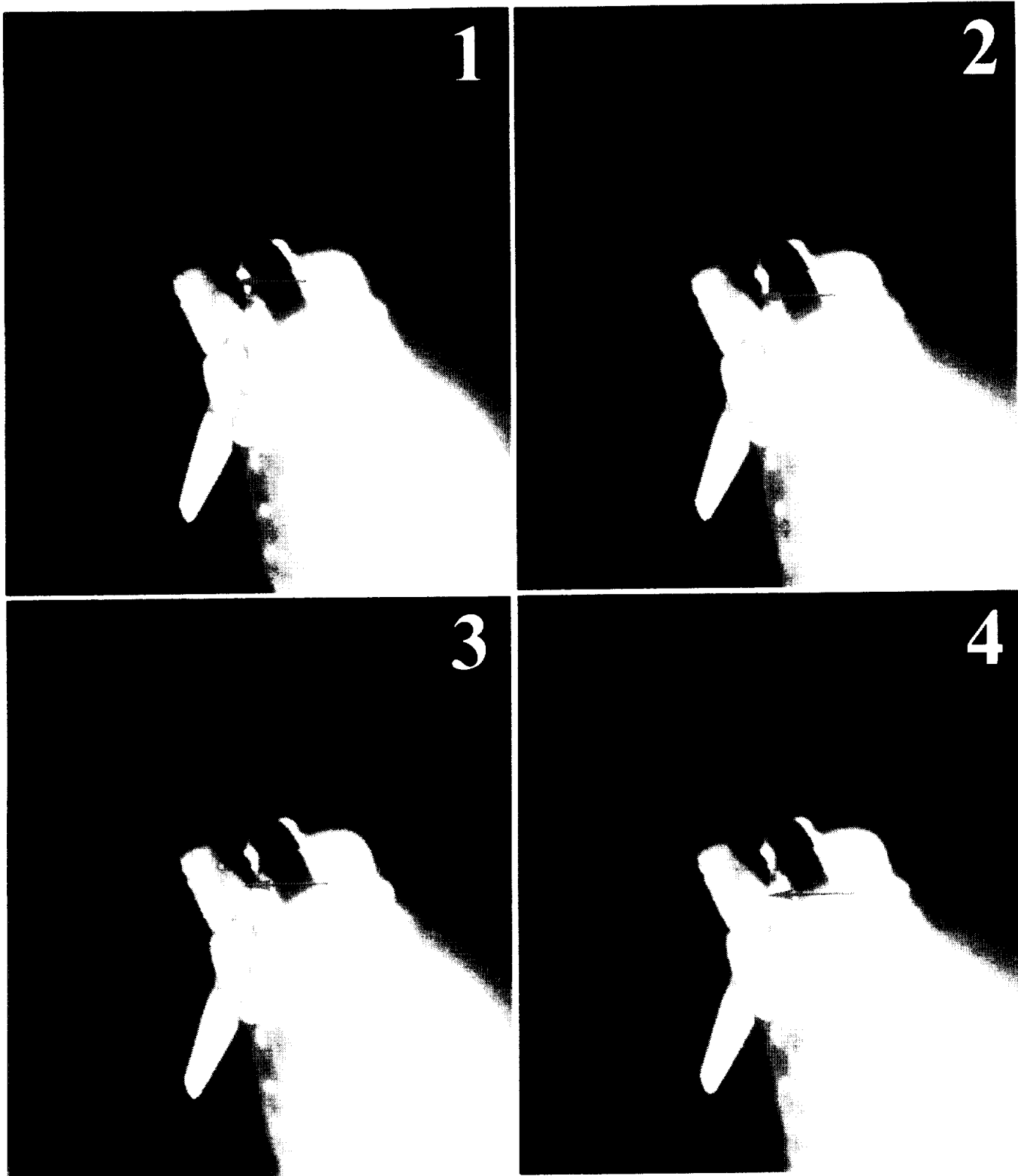




**Photo 14: Debris from RSS/FSS**

TV-21 showed an object believed to be a cable tray cover from the FSS or a PCR panel from the RSS moving westward away from the SSV shortly after T-0. The object appeared to originate from the 135 or 155 foot level of those structures.





**Photo 15: Ice Impacting Orbiter Right Wing**

A debris object, believed to be a piece of ice from the ET LO2 feedline upper bellows, impacted the Orbiter lower surface at 10:11:44.109 GMT (T+34 seconds MET). The ice passed the main landing gear door area (1), continued a trajectory aft (2), impacted and disintegrated at a point that appeared to be about 8 feet forward of the right inboard elevon hinge (3), and created a cloud of ice particles/tile material (4).



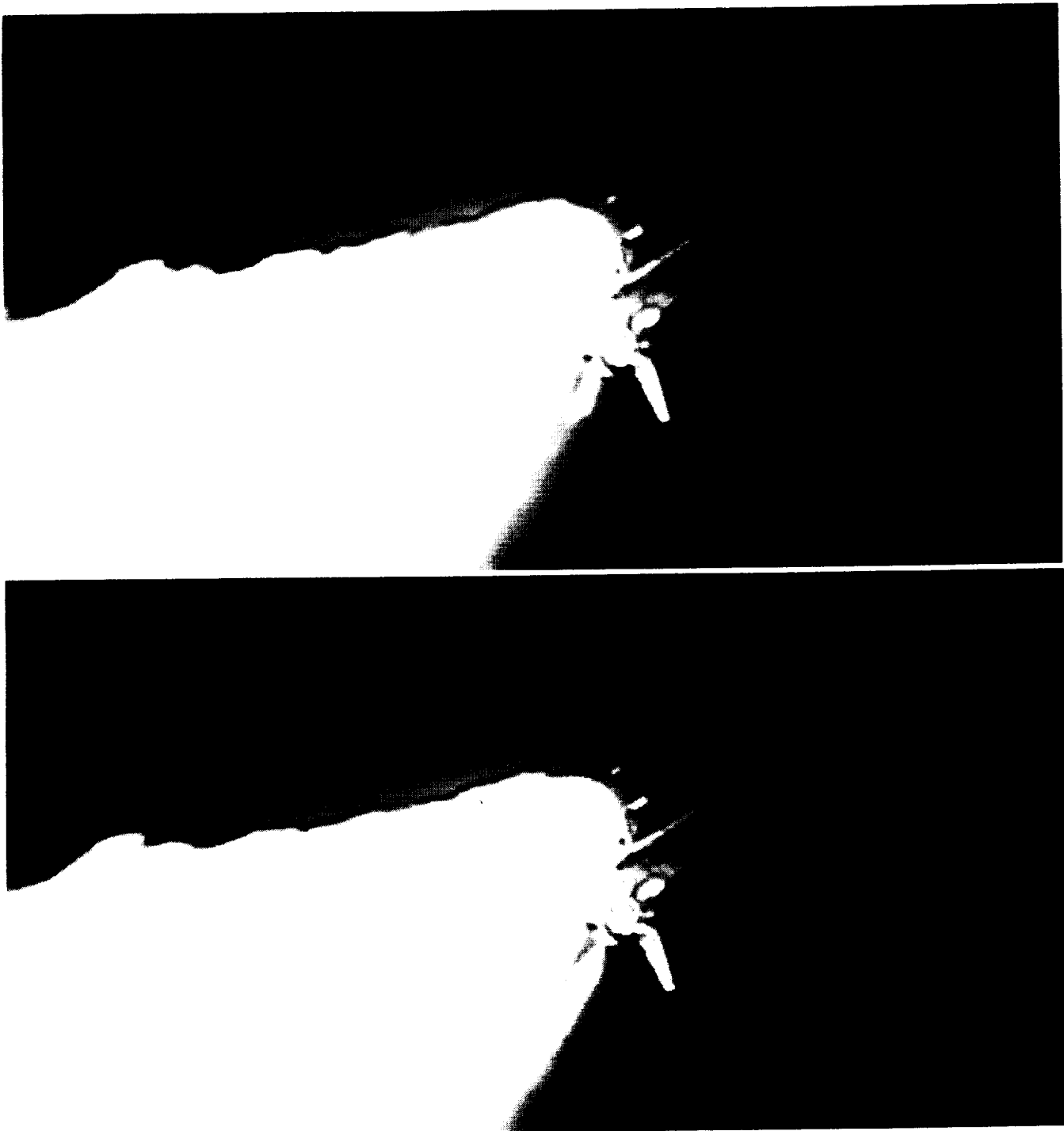




**Photo 16: Vaporous Streak from Right Wing**

The ice impact caused a light-colored, "vaporous" streak to pass the trailing edge of the right inboard elevator. The ice, perhaps 6 inches in length originally, disintegrated upon impact thereby comprising most of the material in the "streak", though there may also have been some tile material as well from the damage site.





**Photo 17: Large Flash in SSME Plume**

A large flare occurred in the SSME #1 exhaust plume at 53 seconds MET for 0.17 seconds duration. This type of flare is usually caused by debris, such as a particle of SRB aft skirt aft ring instafoam, passing through the exhaust plume.



## 6.3 ON-ORBIT FILM AND VIDEO SUMMARY

### 6.3.1 16mm Film Footage

OV-104 was equipped to carry ET/ORB umbilical cameras: 16mm motion picture with 5mm lens and 16mm motion picture with 10mm lens from the LH2 side; 35mm still views from the LO2 side. The 16mm camera with the 5mm lens did not run.

The 16mm film from the camera with 10mm lens was predominantly dark due to time of launch (for SRB coverage) and sun angle/silhouette (during ET separation). So not much detail was discernible.

Most of the left SRB was not in the field of view. The part that was visible indicated a nominal separation.

During ET separation, no damage was noted on the LH2 ET/ORB umbilical with one exception. The forward outboard portion (10 o'clock position) of the purge seal had pulled loose and protruded in the +Z direction.

A debris object passed close to the camera lens in a fore to aft direction as the distance between separated ET and Orbiter increased (frame 7830). Since the object was silhouetted, no detail such as color or surface finish could be discerned. However, due to the large inner diameter, the object was believed to be an O-ring of some type rather than a washer. The origin was not determined.

### 6.3.2 35mm Film Footage

The 35mm still images from the LO2 ET/ORB umbilical camera of the External Tank after separation from the Orbiter were in clear focus. Although the lighting was excellent for areas to the +Y side of the LO2 feedline, the -Y side of the ET was in deep shadow. Consequently, the presence of divots in the LH2 tank-to-intertank flange closeout between the bipods and near the -Y thrust panel could not be confirmed in this film. Also, due to the timing of the +X translation, the film ended before the LO2 tank and nose cone came into view.

No anomalies or missing TPS were detected on the pressurization line ice/frost ramp at XT-1657, which had been repaired the day before launch (reference PR ET-102-TS-0016). The ramp TPS had been damaged by a falling pip pin during platform operations on the launch pad.

A white object, which appeared to be an ice/frost formation approximately 3 inches in diameter, adhered to the +Y longeron TPS closeout in the area where a vertical crack was detected during cryoloading prior to launch. The object protruded far enough to cast a noticeable shadow and may have been a lifted piece of the closeout foam itself, but more likely was condensate/water vapor inside the crack venting at altitude as the atmospheric pressure decreased. Ascent aeroheating probably had decreased enough to permit this moisture to freeze in place.

A divot in the forward surface outboard edge of the +Y vertical strut cable tray closeout was estimated to be 4 inches long by 2 inches wide.

Seven small divots, possibly caused by ice debris impacts, were noted in the +Y thrust strut TPS near the flange/knuckle.

ET LH2 tank and intertank acreage appeared nominal.

The ablation/erosion of LO2 feedline flange closeouts was typical.

### 6.3.3 Crew Hand-Held Still Images

The flight crew obtained 35 images of the External Tank after separation using the hand held Nikon camera. In all of the views, the External Tank was well illuminated by sunlight. Focus was good. However, the ET was somewhat distant (2300 meters) making the detection of small features more difficult. Only the -Z side of the ET was not imaged.

No anomalies were detected on the nose cone. TPS immediately aft of the nose cone was eroded, but the presence of small divots could not be discerned.

A light spot in the LH2 tank-to-intertank flange closeout on centerline between the bipods and a light spot in the LH2 tank-to-intertank flange closeout near the -Y thrust panel may be divots, but could not be confirmed in the other films.

Likewise, a light spot on the -Y thrust strut to longeron interface (knuckle) TPS closeout may be a divot.

Numerous frames showed a light spot on the -Z edge of the +Y longeron TPS closeout mid way between the thrust strut knuckle and the vertical strut that may be a divot.

In other observations, no anomalies were detected on the composite nose cone. Loss of topcoat and erosion of foam in the forward ogive sanded area was visible, but the presence of divots could not be confirmed.

Both +Y and -Y intertank thrust panels, including areas not visible in the two SRB video cameras, exhibited no large divots (5-inches in diameter or greater). Smaller divots could not be discerned due to the subject distance and resolution.

No anomalies were detected in the LO2 and LH2 tank acreage. As expected, the aft dome TPS was darkened by charring, which did not quite reach the XT-2058 ring frame.

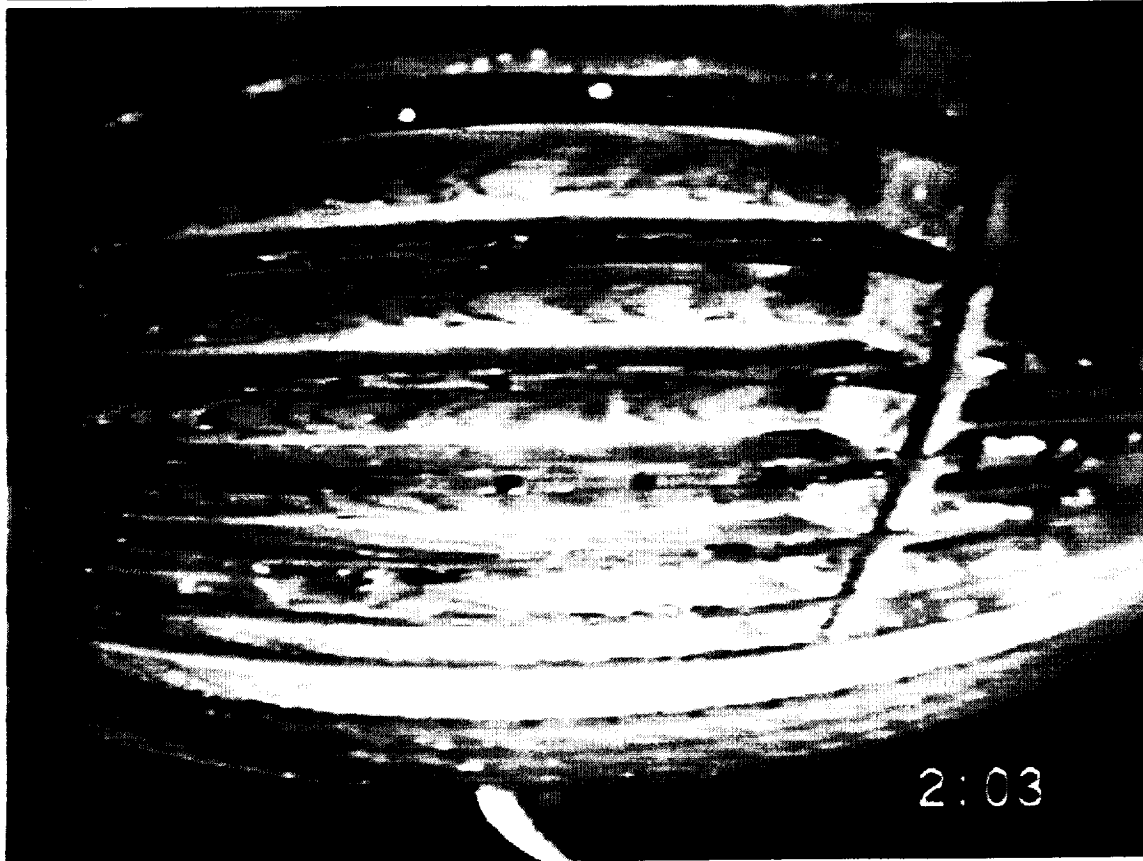
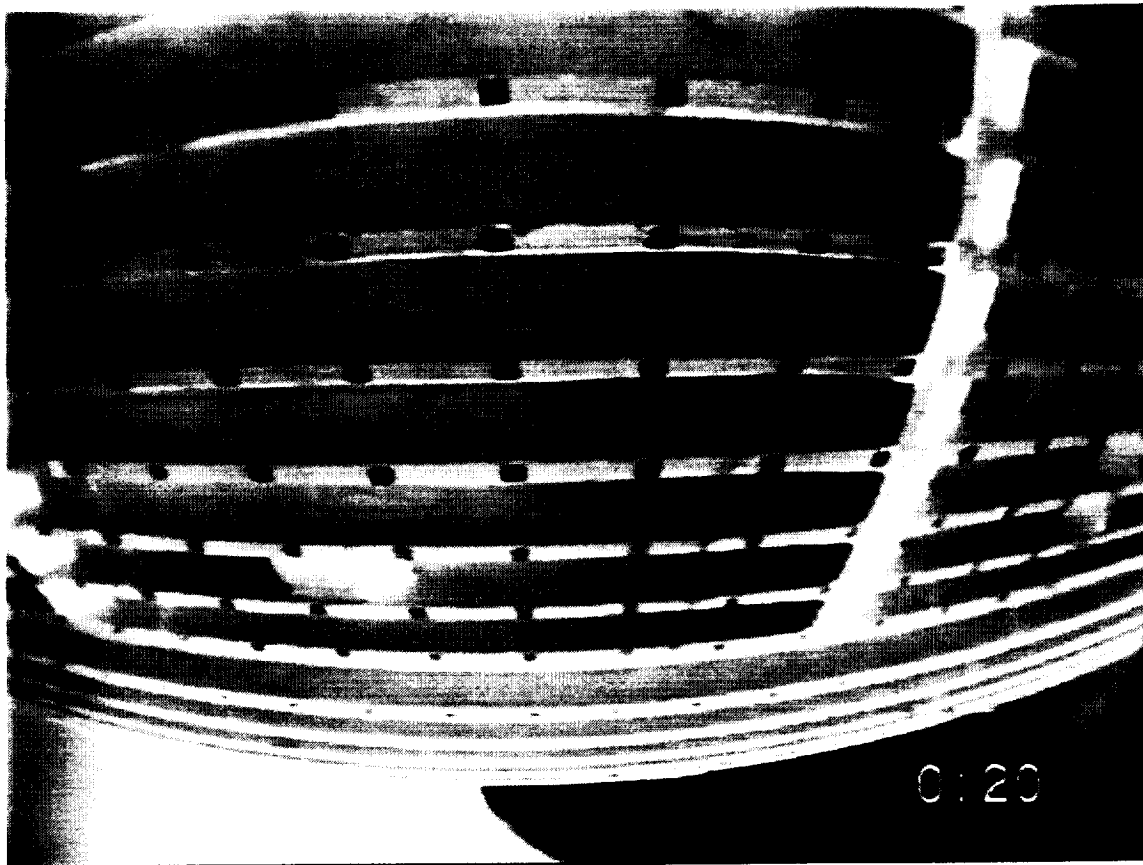


**Photo 18: ET -Y Thrust Panel**

Views of the ET -Y thrust panel at 20 and 123 seconds MET. As expected, divots were smaller in size and fewer in number in the vented areas when compared to the unvented areas. Some very small areas of exposed "new" foam were caused by normal ascent recession/erosion and not included in the total divot count. Divots were very shallow with no primed substrate visible. Most divots were small and less than 0.5 inches in diameter.



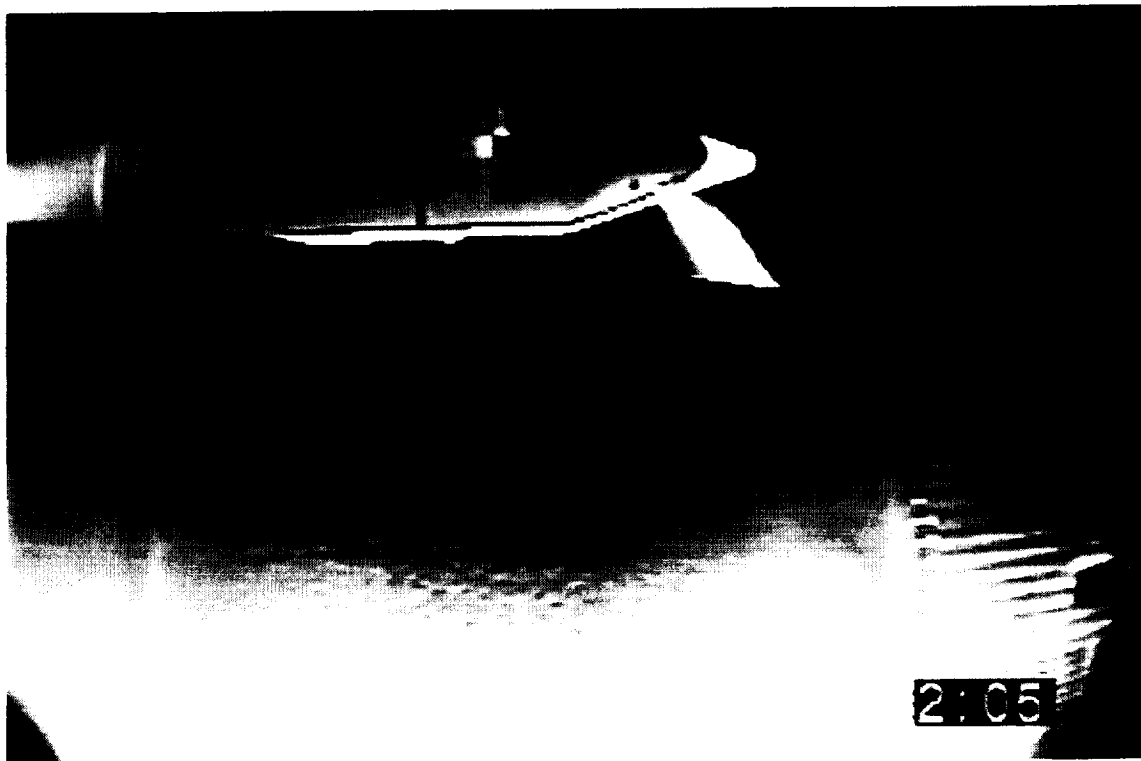
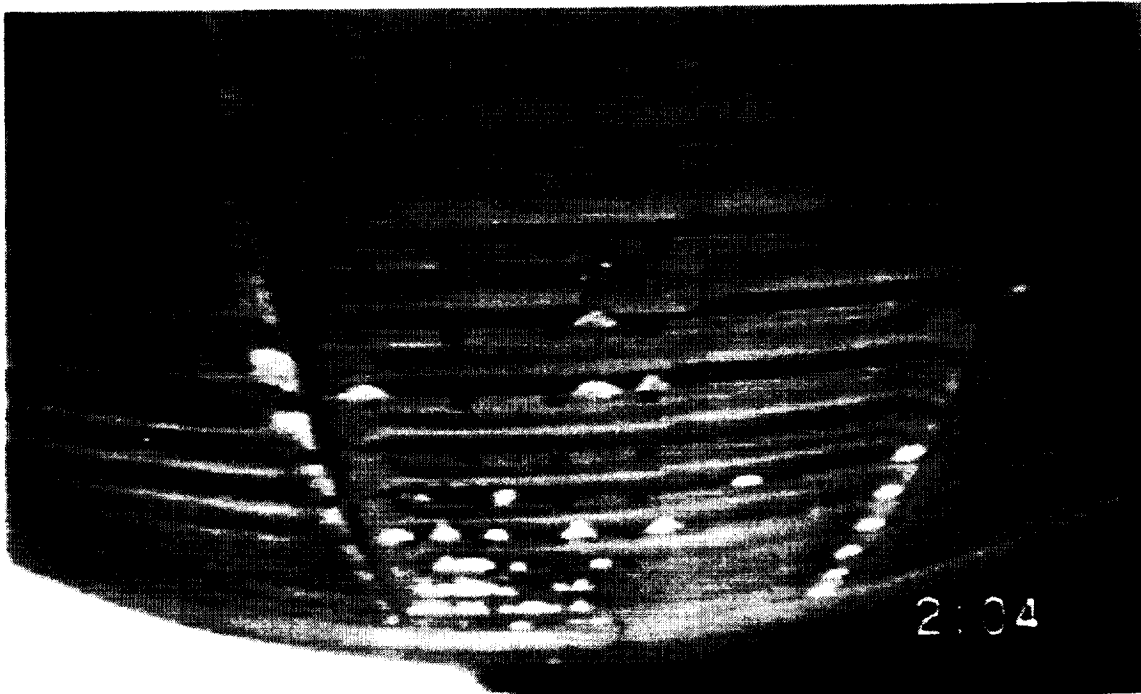




**Photo 19: ET +Y Thrust Panel**

Views of the ET +Y thrust panel at 20 and 123 seconds MET. As expected, divots were smaller in size and fewer in number in the vented areas when compared to the unvented areas (note larger divots in the right side of the frame). Generally, divots in vented areas were less than 0.5 inches in diameter and shallow in depth.

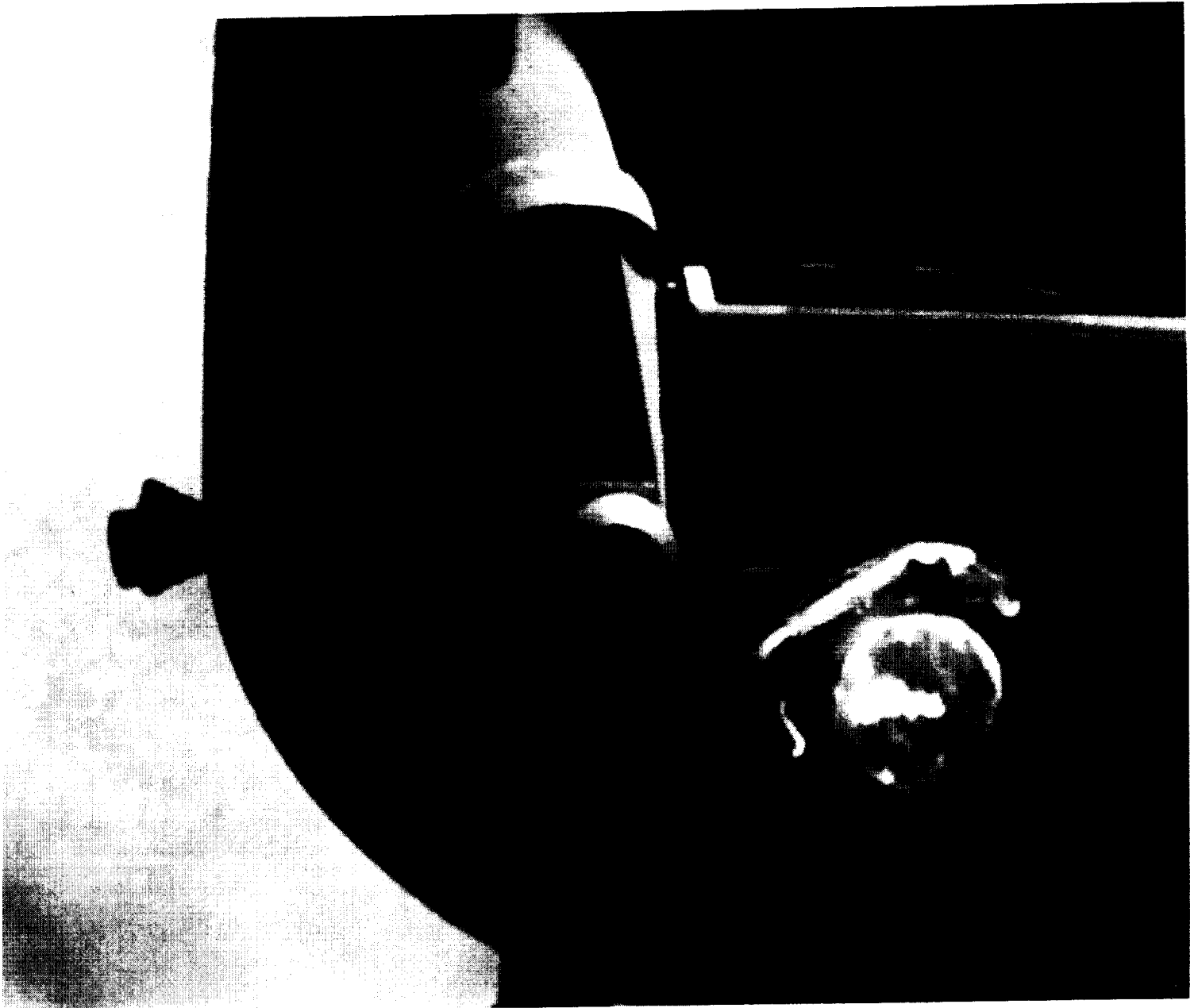




**Photo 20: Divot on -Z Side**

At the start of SRB separation from the External Tank, the camera had a more direct view of the larger divots located in intertank stringers where the TPS was not vented. Bottom photo shows a divot approximately 9-inches in diameter on the ET -Z side acreage just aft of the intertank-to-LH2 tank splice.

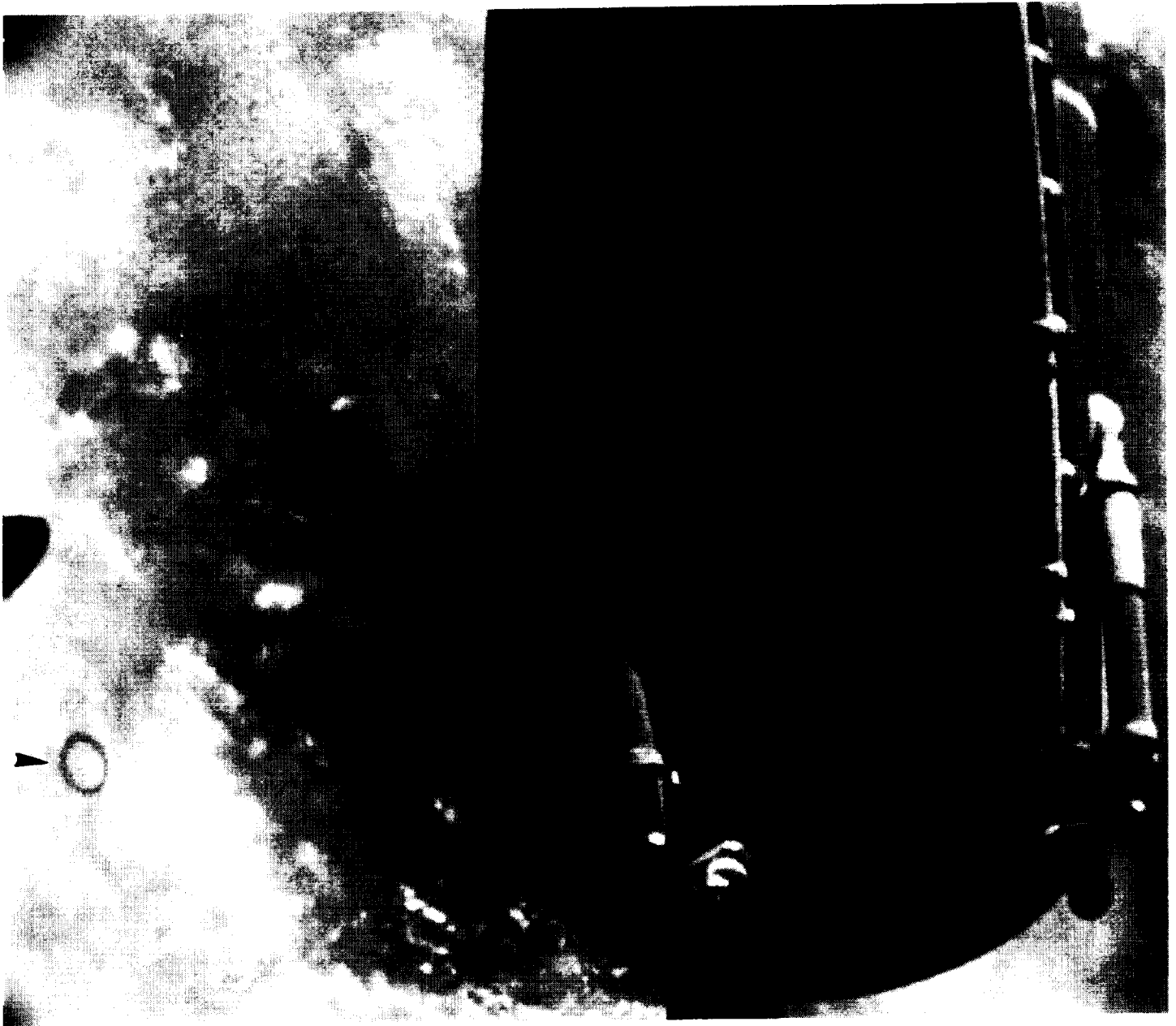




**Photo 21: Protruding Purge Seal**

During ET separation, no damage was noted on the LH2 ET/ORB umbilical with one exception. The forward outboard portion (10 o'clock position) of the purge seal had pulled loose and protruded in the +Z direction.



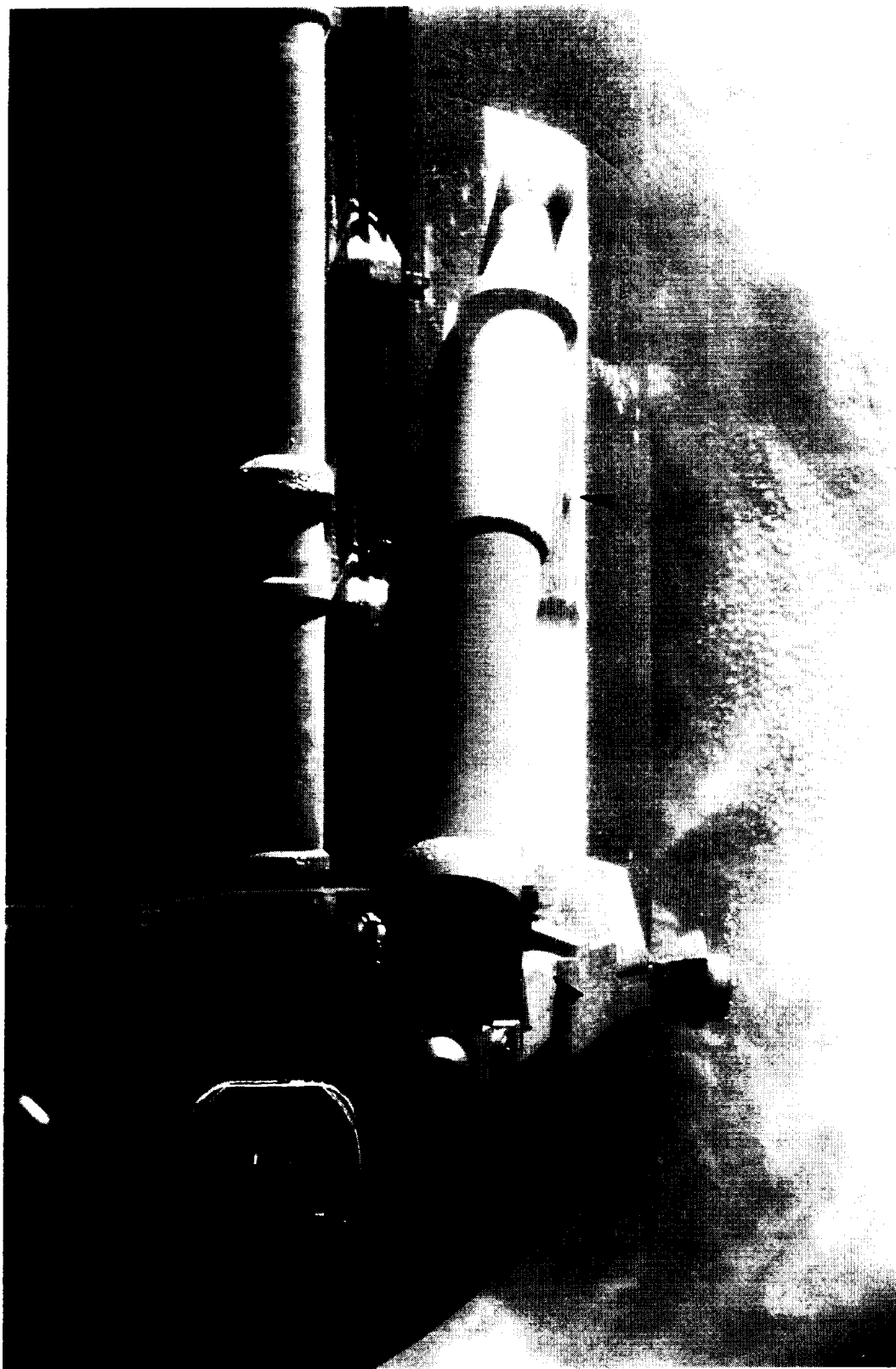


**Photo 22: Loose O-Ring**

A debris object passed close to the camera lens in a fore to aft direction as the distance between separated ET and Orbiter increased. Since the object was silhouetted, no detail such as color or surface finish could be discerned. However, due to the large inner diameter, the object was believed to be an O-ring of some type rather than a washer. The origin was not determined.



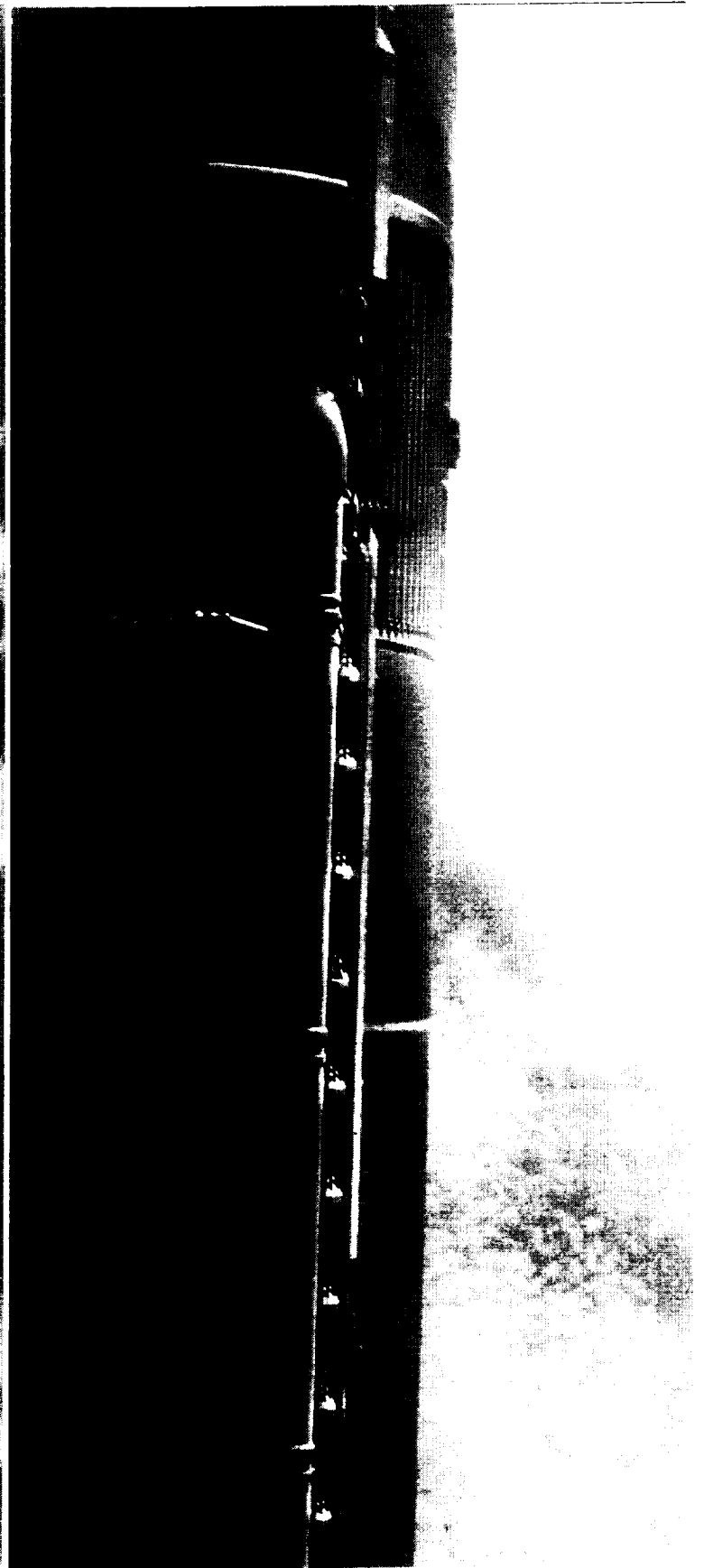
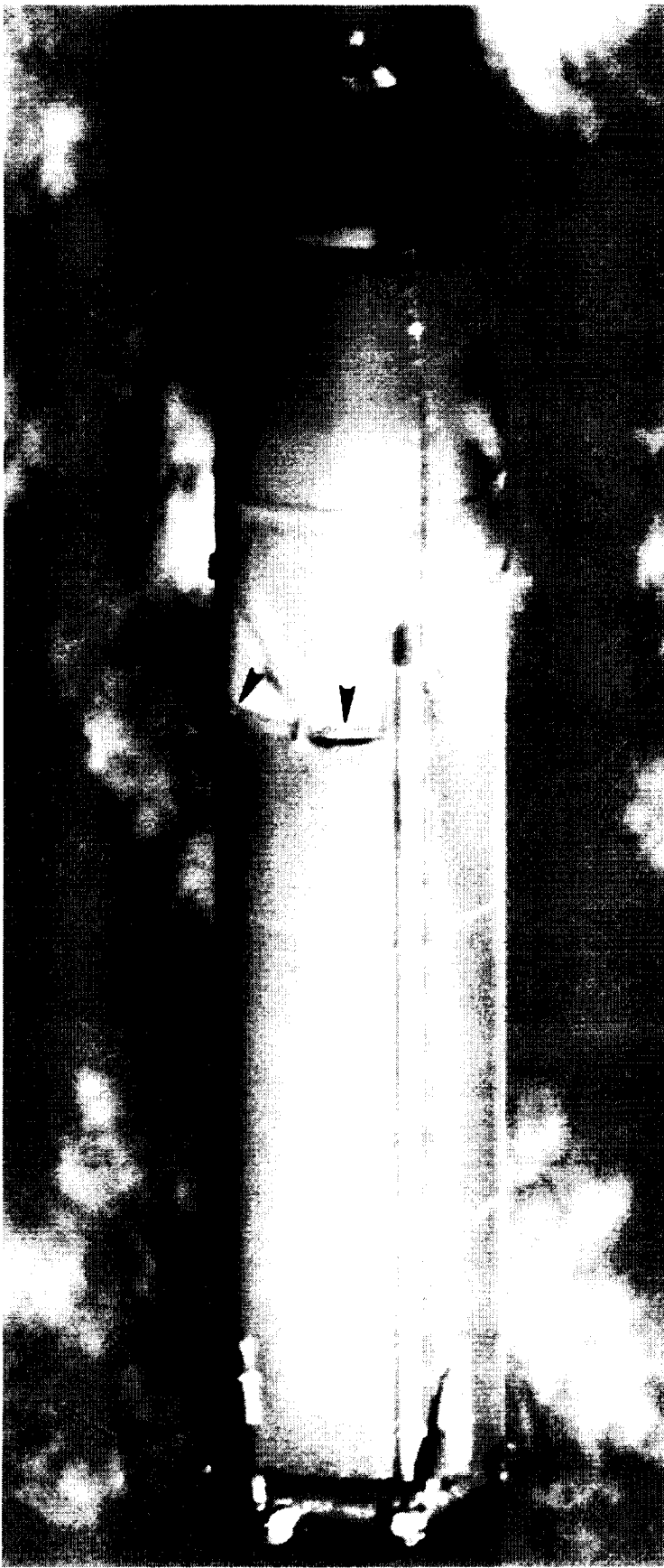




**Photo 23: ET After Separation**

A white object, which appeared to be an ice/frost formation approximately 3 inches in diameter, adhered to the +Y longeron TPS closeout in the area where a vertical crack was detected during cryoloading prior to launch (arrow). The object protruded far enough to cast a noticeable shadow and may have been a lifted piece of the closeout foam itself, but more likely was condensate/water vapor inside the crack venting at altitude as the atmospheric pressure decreased. Ascent aeroheating probably had decreased enough to permit this moisture to freeze in place. A divot in the forward surface outboard edge of the +Y vertical strut cable tray closeout was estimated to be 4 inches long by 2 inches wide (arrow).

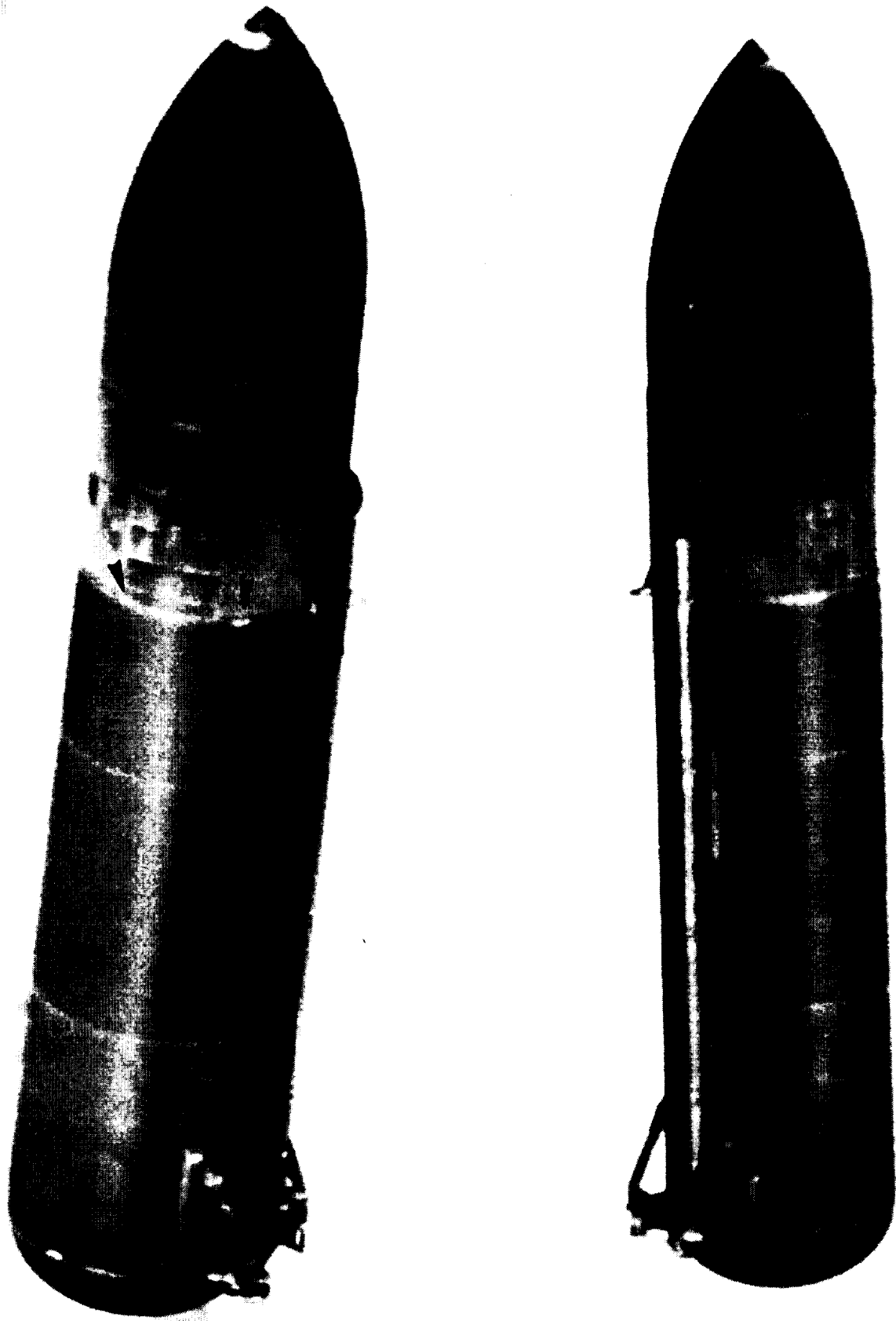




**Photo 24: ET Intertank Area**

Crew hand held image shows possible divots in the LH2 tank-to-intertank splice between the bipods and near the -Y thrust panel (arrows, left photo). However, view from the 35mm camera in the ET/ORB LO2 umbilical could not confirm the presence of the divots due to shifted field of view and deep shadow (right photo).





**Photo 25: ET Thrust Panels**

Crew hand held images show no large divots in either thrust panel - that would be discernible with the given image resolution and subject distance. Yet three 9-inch diameter divots are readily visible in the LH2 tank-to-intertank splice (arrows).



## **6.4 LANDING FILM AND VIDEO SUMMARY**

A total of 17 films and videos, which included eight 35mm large format films and nine videos, were reviewed. There was not much detail for engineering assessment due to the dark conditions of a night landing.

The landing gear extended properly. The infrared scanners showed no debris falling from the Orbiter during final approach.

Runway centerline cameras showed right wing slightly low during final approach to counteract the effects of the crosswind, but then virtually level for main landing gear touchdown.

Drag chute deployment, which occurred before the nose wheel contacted the runway, appeared normal. No anomalies were detected from touch down through rollout.

## **7.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT**

The BI-101 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAFS Hangar AF on 22 May 2000. Both boosters were in excellent condition.

The frustums exhibited no debonds/unbonds or missing TPS.

All eight BSM aero heat shield covers had locked in the fully opened position.

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact, though one layer of the RH SRB +Z base plate had delaminated.

The Field Joint Protection System (FJPS) and the System Tunnel Covers closeouts were generally in good condition with no unbonds observed. A greater than usual amount of Hypalon paint was missing from cork closeouts, particularly on the GEI, cable runs, etc. The paint was missing predominantly from the systems tunnel side of the right SRB and the +Z side of the left SRB.

A sooted, 3/8-inch long by 5/8-inch wide by 1/4-inch deep gouge was detected on the leading edge of the RH SRB center field joint at approximately 220 degrees. However, there were no streaks on the adjacent white segment case leading to the gouge. The damage site will be sampled for laboratory analysis.

Separation of the aft ET/SRB struts appeared normal.

Foam was missing from the aft side of both left and right IEA's. The exposed substrate was sooted.

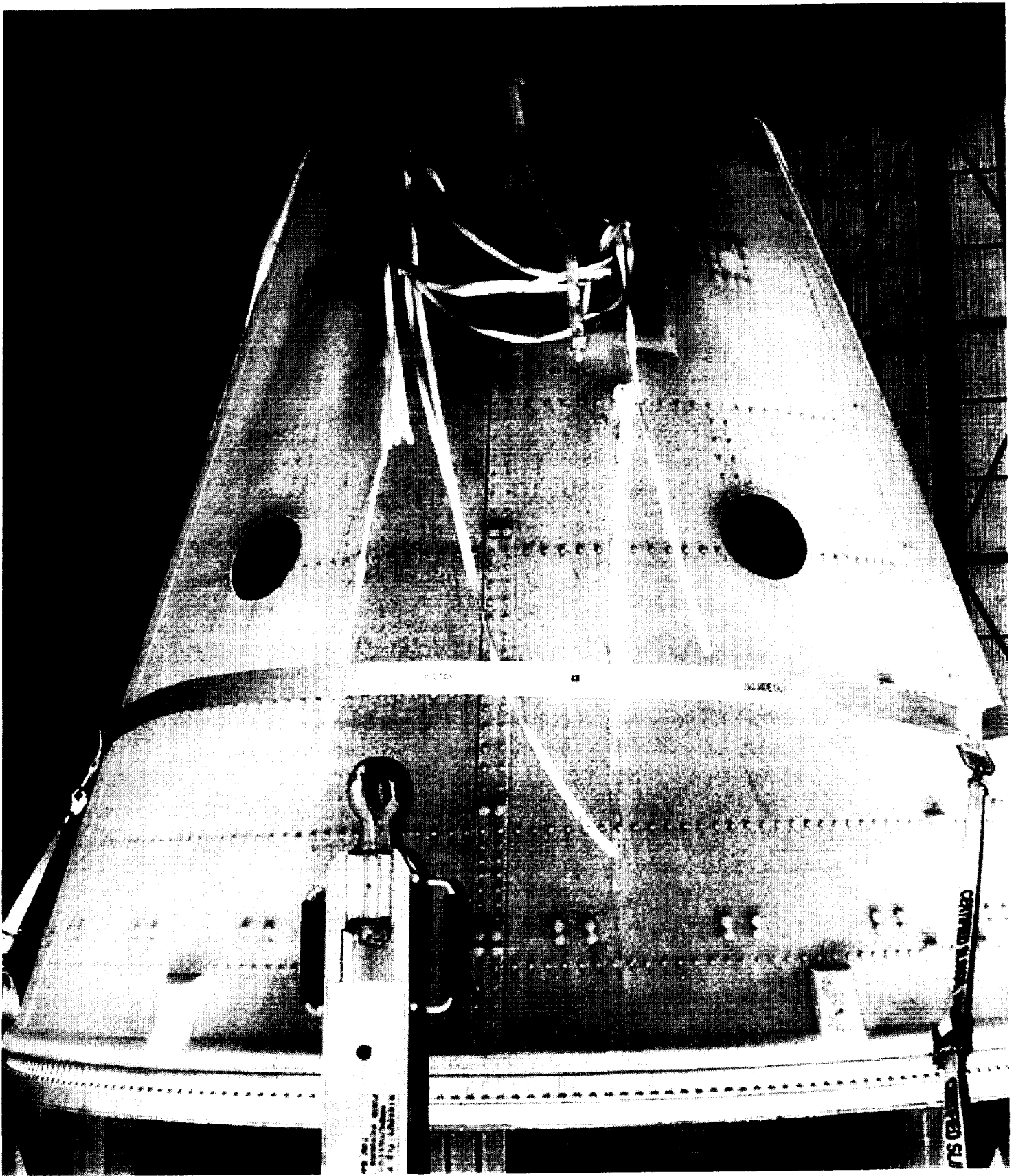
Aft skirt external surface TPS was nominal and in good condition. Typical blistering of Hypalon paint had occurred on the BTA insulation close-outs.

The holddown post Debris Containment Systems (DCS) appeared to have functioned normally, though the #2, #3, #5, and #7 plungers were not fully seated and were obstructed by frangible nut pieces as a result of water impact.

There was no evidence of a stud hang-up on this launch.

Overall, the external condition of both SRB's was excellent.

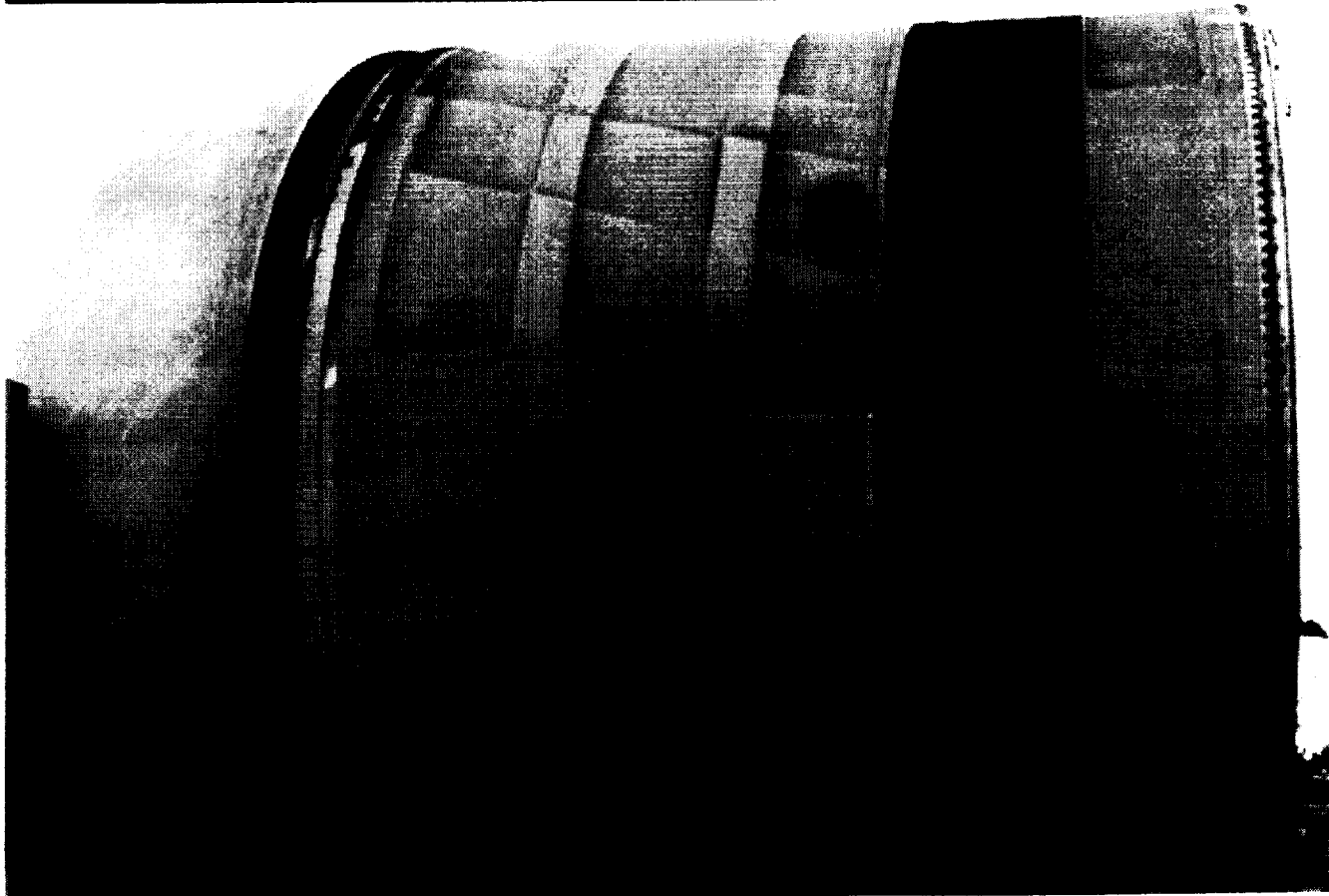
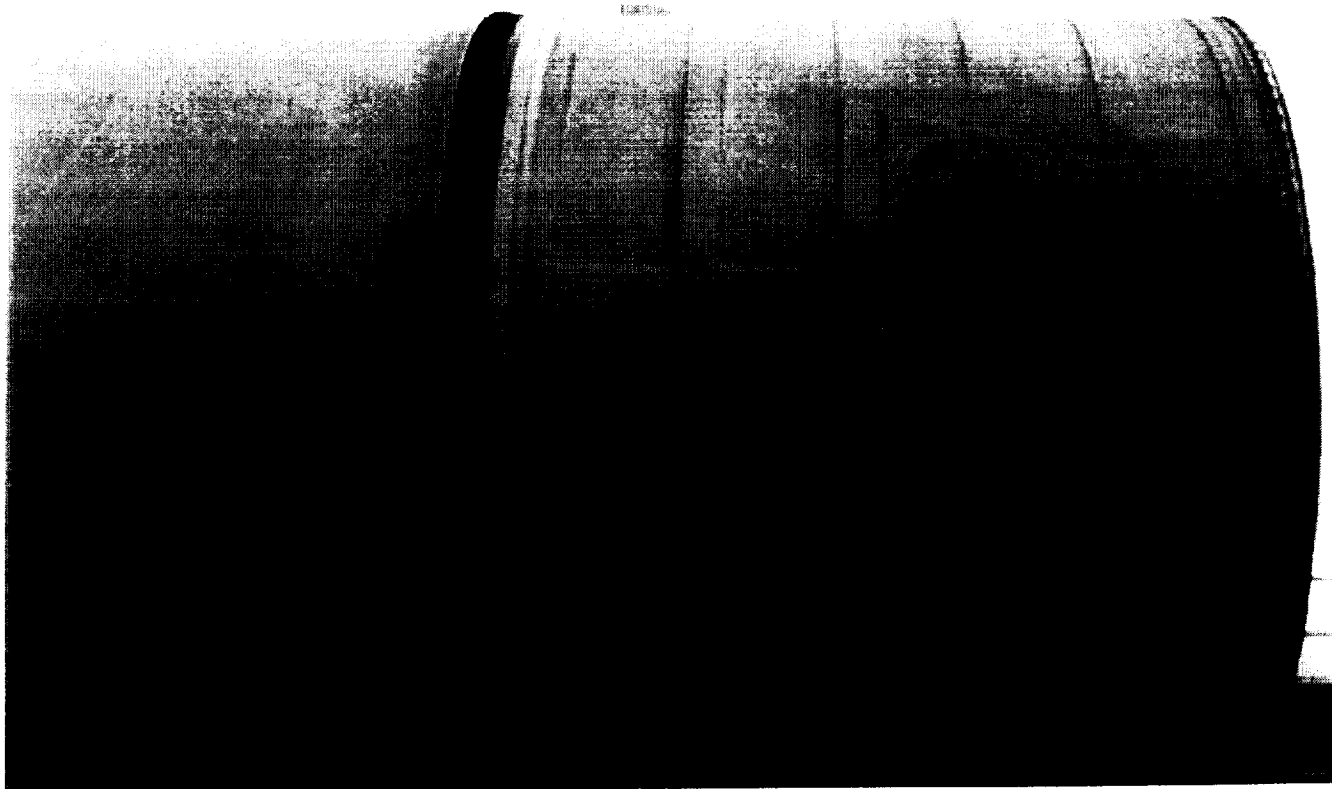




**Photo 26: Frustum Post Flight Condition**

The frustums exhibited no debonds/unbonds or missing TPS.  
All eight BSM aero heat shield covers had locked in the fully opened position.

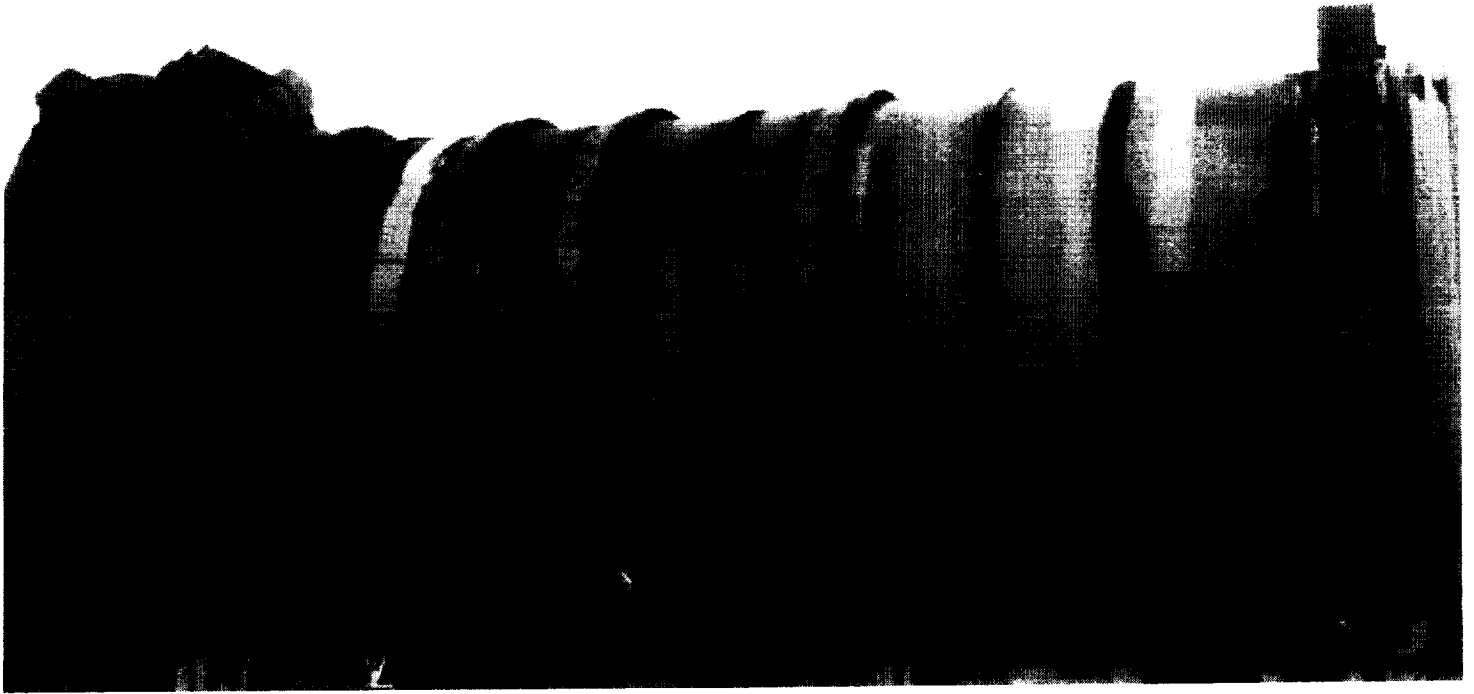




**Photo 27: Forward Skirt Post Flight Condition**

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact, though one layer of the RH SRB +Z base plate had delaminated.





**Photo 28: Aft Skirt Post Flight Condition**  
Aft skirt external surface TPS was in good condition



## 8.0 ORBITER POST LANDING DEBRIS ASSESSMENT

After the 2:20 a.m. local/eastern time landing on 29 May 2000, a post landing inspection of OV-104 Atlantis was conducted at the Kennedy Space Center on SLF runway 15 and in Orbiter Processing Facility bay 3. This inspection was performed to identify debris impact damage and, if possible, debris sources.

The Orbiter TPS sustained a total of 113 hits, of which 27 had a major dimension of 1-inch or larger. This total does not include the numerous hits on the base heat shield attributed to SSME vibration/acoustics and exhaust plume recirculation (reference Figures 1-4).

The following table lists the STS-101 Orbiter debris damage hits by area:

	<u>HITS &gt; 1-inch</u>	<u>TOTAL HITS</u>
Lower surface	19	70
Upper surface	0	0
Window Area	3	16
Right side	2	7
Left side	2	7
Right OMS Pod	0	4
Left OMS Pod	1	9
TOTALS	27	113

The Orbiter lower surface sustained 70 total hits, of which 19 had a major dimension of 1-inch or larger. Some of these damage sites (23 hits with 5 larger than 1-inch) were located in the area from the nose gear to the main landing gear wheel wells on both left and right chines, which is consistent with the loss of foam from the ET thrust panels. But the overall quantity and average size of the damage sites compared to previous flights were consequently reduced as a result of the pre-launch TPS venting modification. And some of the hits in this area may also be attributed to impacts from LO2 feedline bellows ice particles.

In general, the lower surface tile damage on this flight was considered to be a return to fleet averages, or “in family” (reference Figures 5-7). The comparative database will now reflect the mission set STS-70 through STS-85. These missions are significant because debris control measures had been optimized and debris damage sites on the Orbiter correspondingly minimized for each flight. Missions STS-86 through STS-103 are considered “out of family” due to the loss of TPS from External Tank thrust panels, a known debris source, and therefore outside the data base of random occurrences. With the incorporation of the successful – and full scale - TPS venting modification, missions flown after STS-103 will now be included in the database. Data from subsequent missions will be compared against the adjusted database and any data points outside the 3-sigma variation will be investigated as a new problem.

The largest lower surface tile damage site, located on the left wing immediately forward of the inboard elevon hinge, measured 8-inches long by 1.25-inches wide by 0.75-inches deep. The cause of this damage site has not been determined. However, it should be noted the damage site typically erodes during re-entry and may have initially been half the size listed above. Referencing the Debris Trajectory Database showed potential points of origin on the forward and mid segments of the left SRB, so it is possible a small, high density particle, such as a piece of cork or BTA may have come loose in flight.

Likewise, a lower surface tile (V070-191009-161) damage site on the right wing, approximately 10 feet forward of the right inboard elevon hinge, corresponded to the debris object impact detected in launch film E-224. The damage site measured 5.25-inches long by 1.5-inches wide by 0.5-inches deep, though re-entry erosion had enlarged this damage site as well. Due to the “gouge like” appearance and depth, this damage site was caused by a debris object with a greater density than ET foam, such as ice from the ET LO2 feedline bellows. Several tile hits aft of this location may have been the result of secondary impacts.

Again referencing the Debris Trajectory Database, Boeing analysts found 10 cases having impact locations closest to the actual impact location for the two Mach Numbers 0.60 and 1.05 closest to the actual flight Mach Number of 0.75. The majority of the closest cases corresponded to the density of ice (30-57 pcf). Therefore, the most likely source of the ice debris was the ET LO2 feedline upper bellows. The composition of the “vaporious streak” detected in the launch films was a mixture of ice debris and damaged tile material particles.

Numerous tile hits around the ET/ORB umbilicals were attributed to impacts from umbilical ice or shredded pieces of umbilical purge barrier material flapping in the airstream.

The main landing gear tires were reported to be in good condition for a landing on the KSC concrete runway. There was no ply under cutting on the main landing gear tires.

ET/Orbiter separation devices EO-1, EO-2, and EO-3 functioned normally. No ordnance fragments were found on the runway beneath the umbilicals. The EO-2 and EO-3 fitting retainer springs appeared to be in nominal configuration, though two of the EO-2 “salad bowl” clips were missing. No umbilical closeout foam or white RTV dam material adhered to the umbilical plate near the LH2 recirculation line disconnect.

Less than usual amounts of tile damage occurred on the base heat shield. All SSME Dome Heat Shield closeout blankets were in excellent condition.

No unusual tile damage occurred on the leading edges of the OMS pods and vertical stabilizer. Drag chute deployment caused a 2-inch long by 1-inch wide by 1/8-inch deep damage site on a stinger tile. On the inside edge of the upper right split rudder, a 3.5-inch by 1-inch piece of black tile surface coating material was missing and may have been the result of SSME ignition acoustics or vibration.

Damage sites on the window perimeter tiles was less than usual in quantity and size. Hazing and streaking of forward-facing Orbiter windows was moderate. An 8-inch long streak on window #2 led to a damage site in an upper right corner perimeter tile. The largest damage site, also located in window #2 perimeter tiles, was approximately 1.5-inches long by 0.75-inches wide. This damage may be attributed to impacts from FRCS thruster paper covers and RTV adhesive.

The post landing walkdown of Runway 15 was performed immediately after landing. No unexpected flight hardware was found. All components of the drag chute were recovered and appeared to have functioned normally. Both reefing line cutter pyrotechnic devices were expended.

In summary, the total number of Orbiter TPS debris hits, and the number of hits 1-inch or larger, were “in family”.



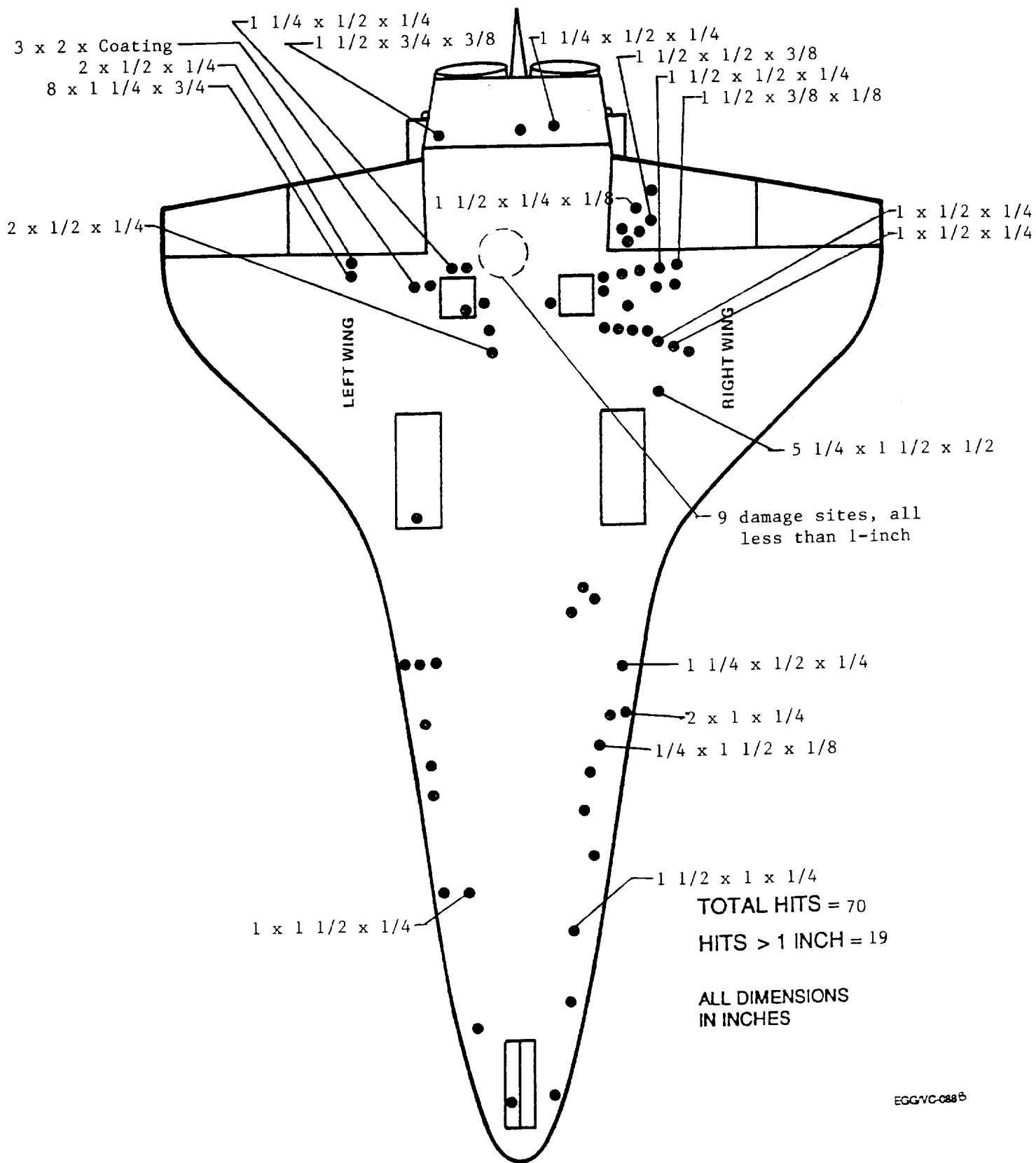


Figure 1: Orbiter Lower Surface Debris Damage Map

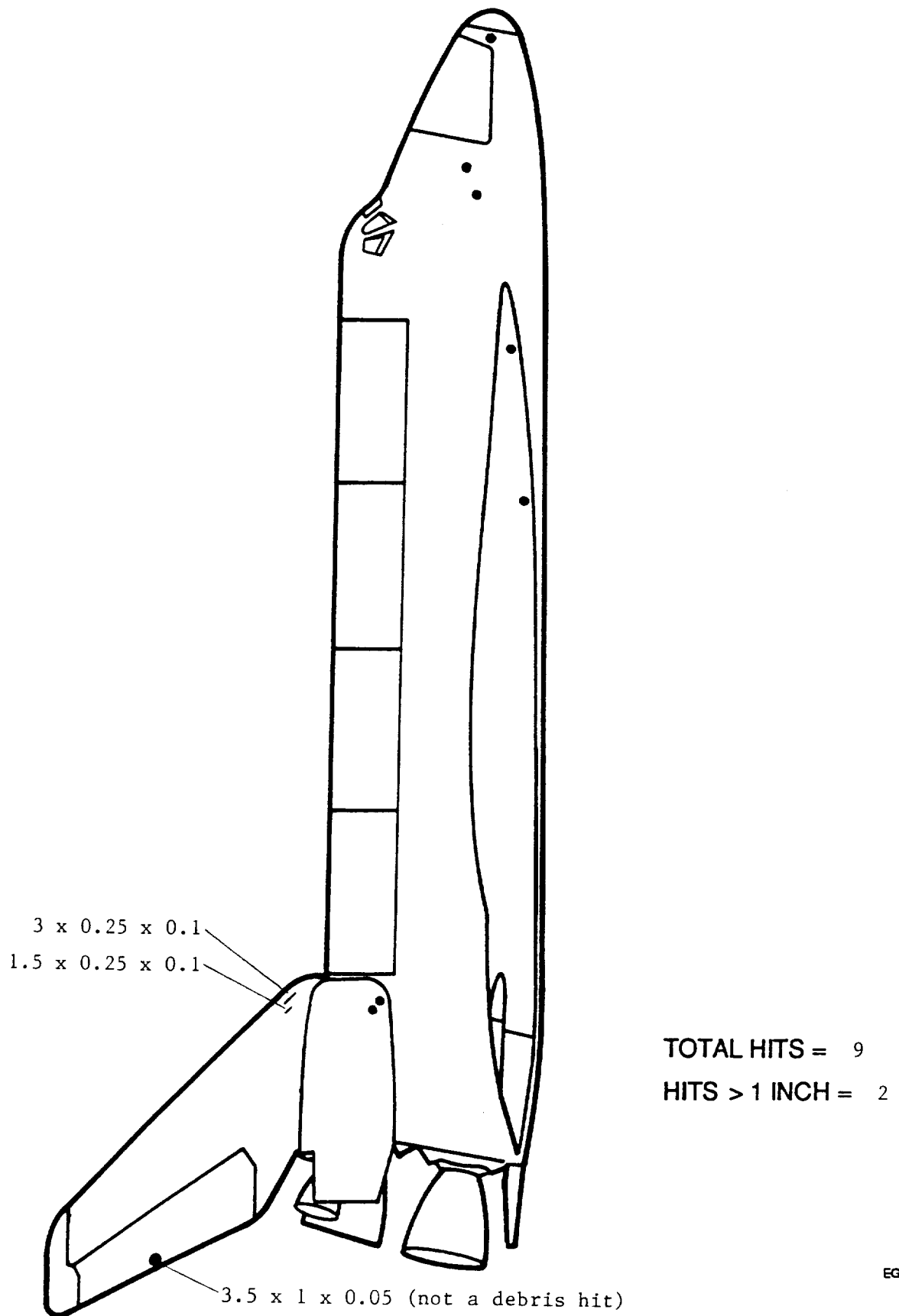


Figure 2: Orbiter Right Side Debris Damage Map

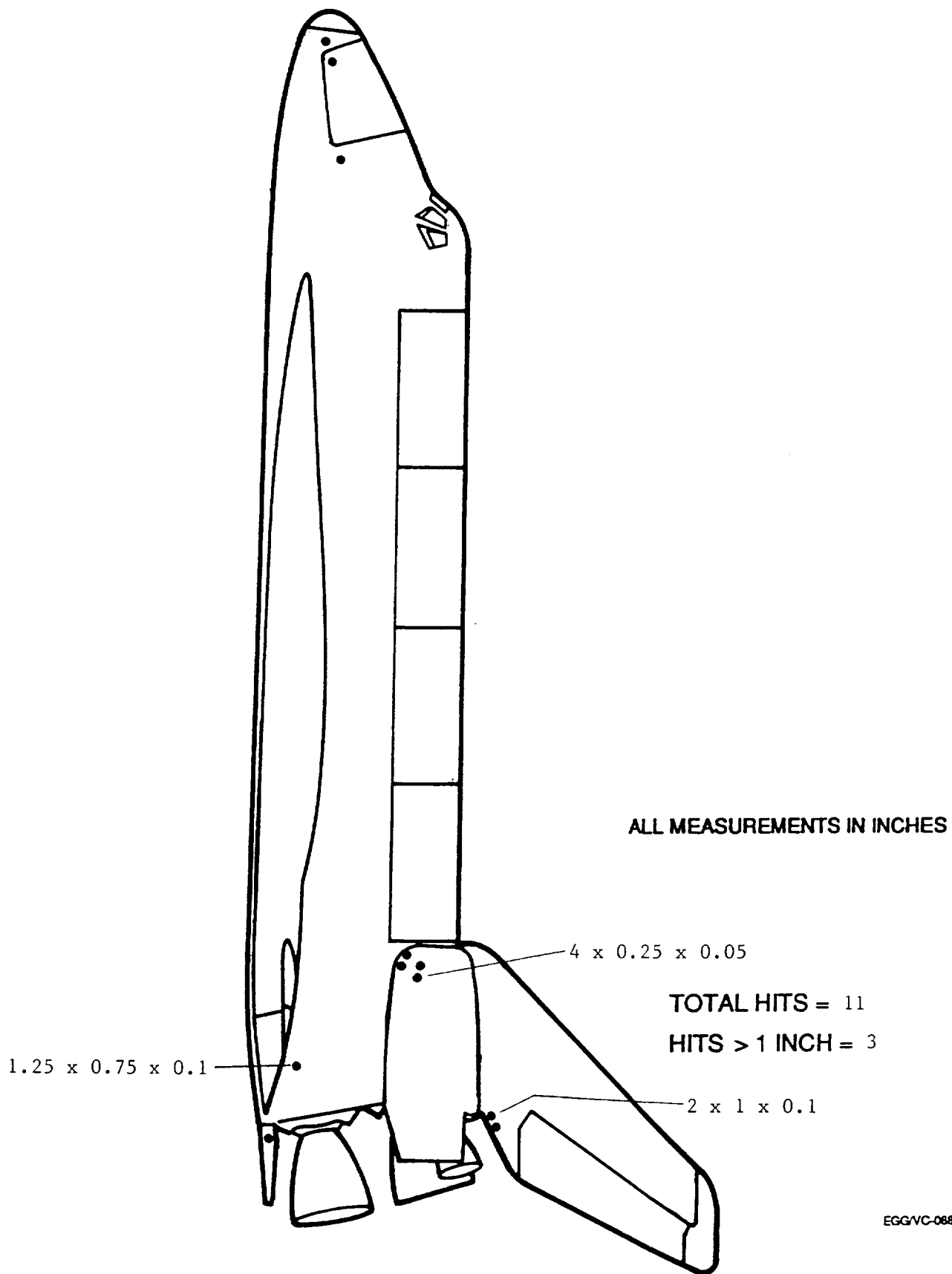


Figure 3: Orbiter Left Side Debris Damage Map

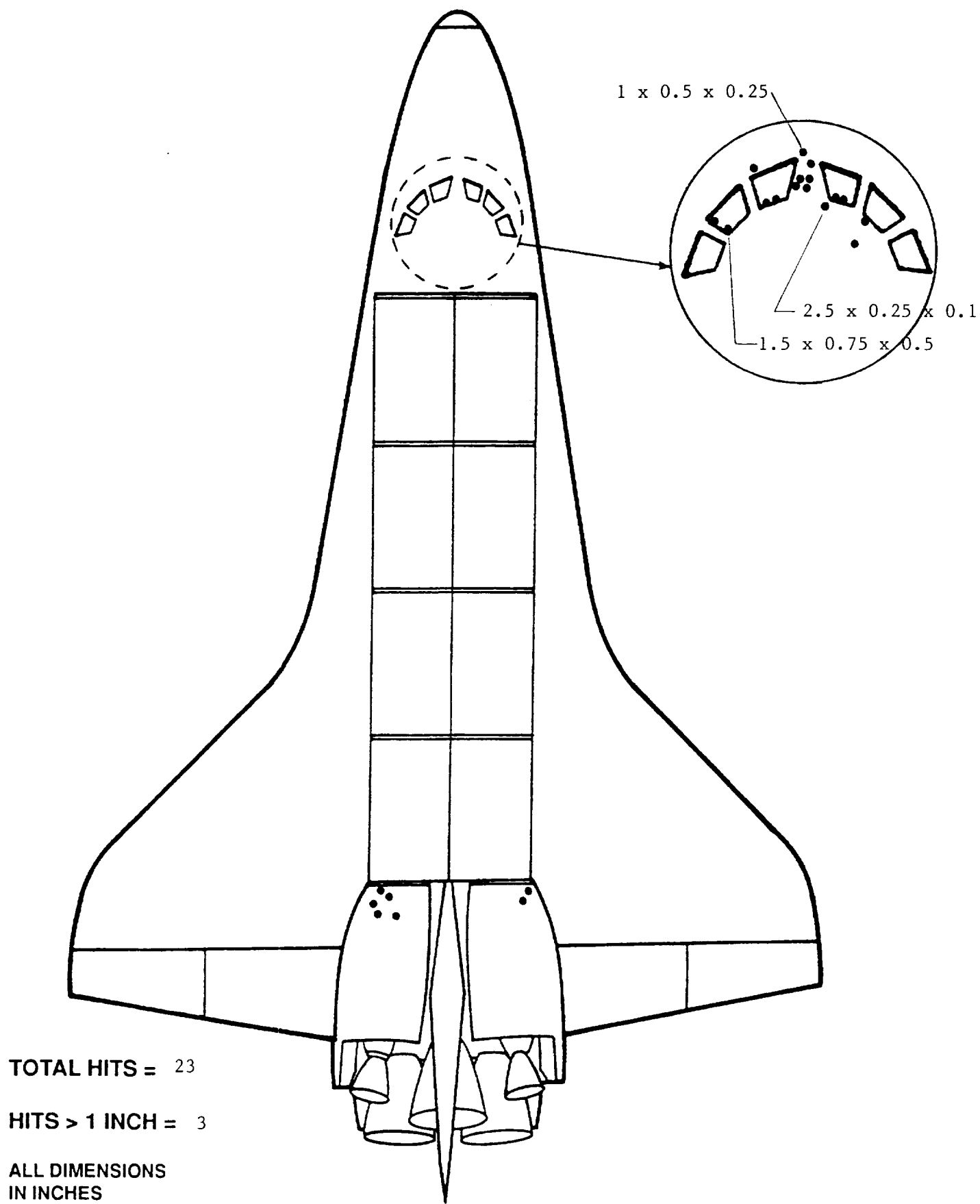


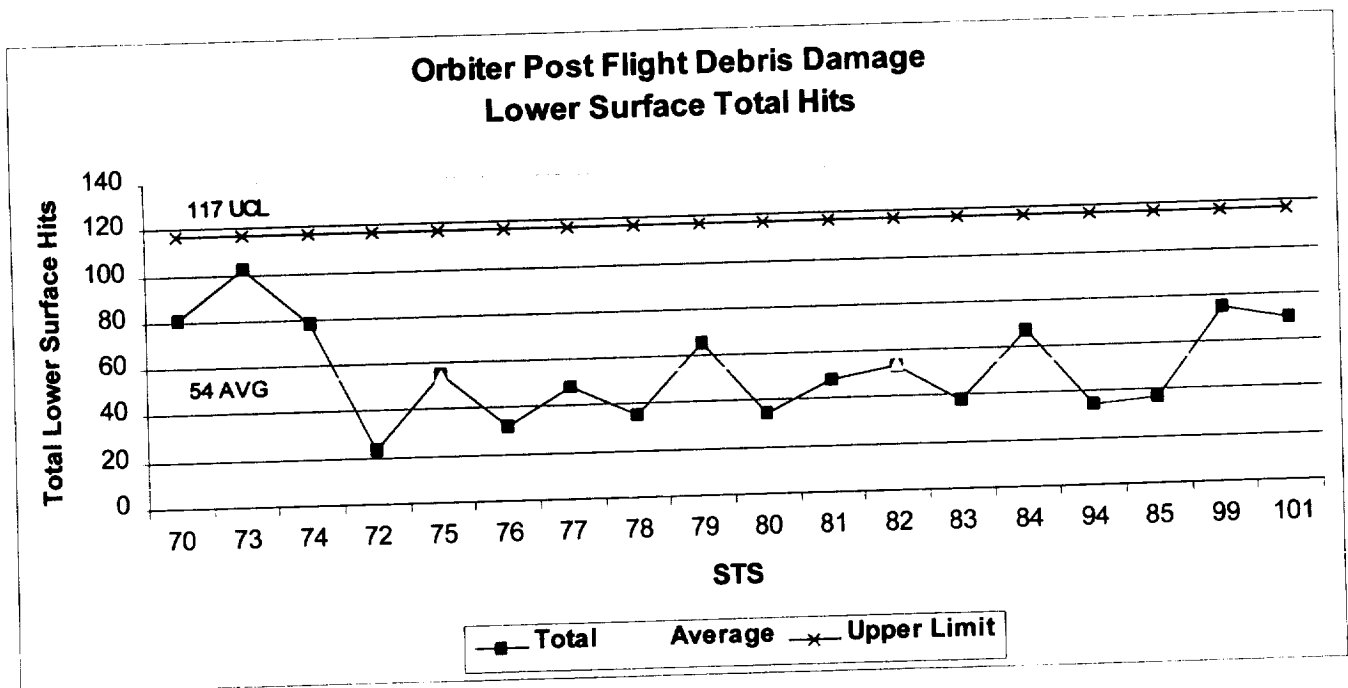
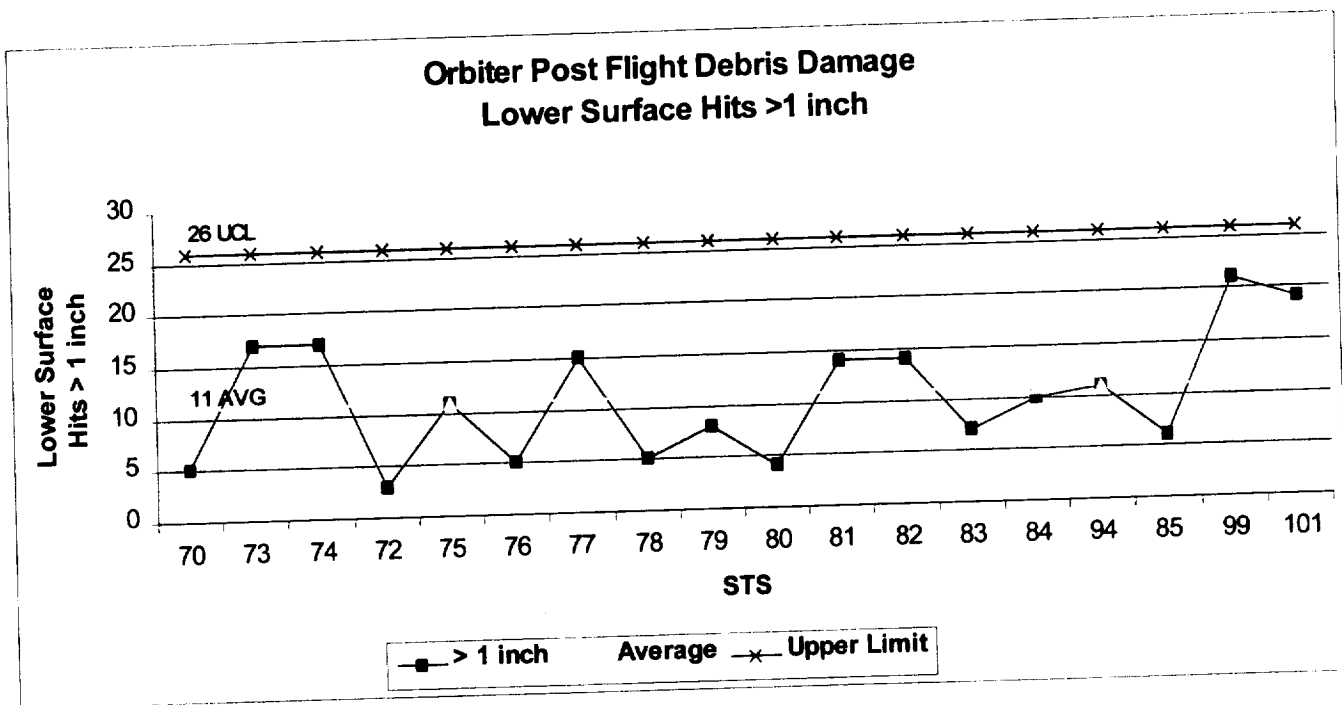
Figure 4: Orbiter Upper Surface Debris Damage Map

STS NUMBER	LOWER SURFACE		ENTIRE SURFACE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
STS-70	5	81	9	127
STS-69	22	175	27	198
STS-73	17	102	26	147
STS-74	17	78	21	116
STS-72	3	23	6	55
STS-75	11	55	17	96
STS-76	5	32	15	69
STS-77	15	48	17	81
STS-78	5	35	12	85
STS-79	8	65	11	103
STS-80	4	34	8	93
STS-81	14	48	15	100
STS-82	14	53	18	103
STS-83	7	38	13	81
STS-84	10	67	13	103
STS-94	11	34	12	90
STS-85	6	37	13	102
STS-99	21	75	25	88
AVERAGE	10.8	60.0	15.4	102.1
SIGMA	5.9	35.6	6.1	31.6
STS-101	19	70	27	113

MISSIONS STS-86,87,89,90,91,95,88,96,93,103 ARE NOT INCLUDED SINCE THESE MISSIONS HAD SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS SOURCES

**Figure 5: Orbiter Post Flight Debris Damage Summary**

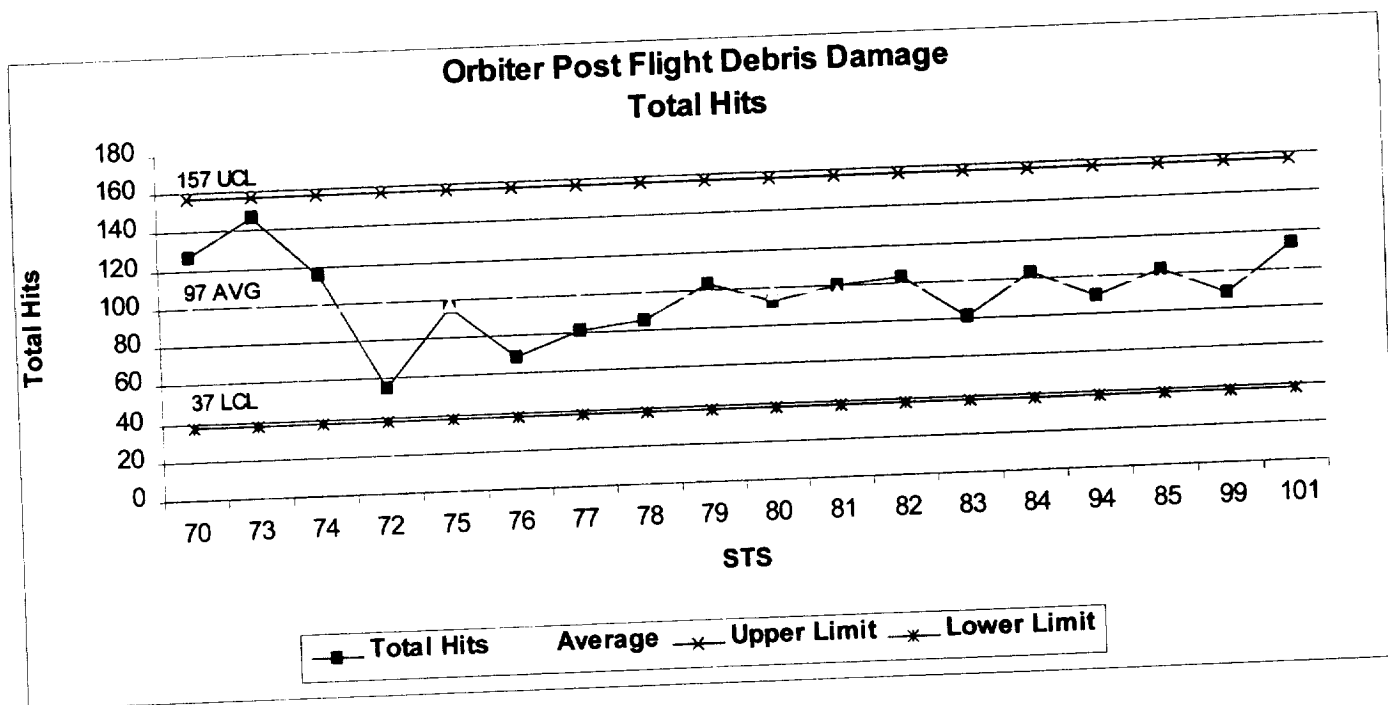
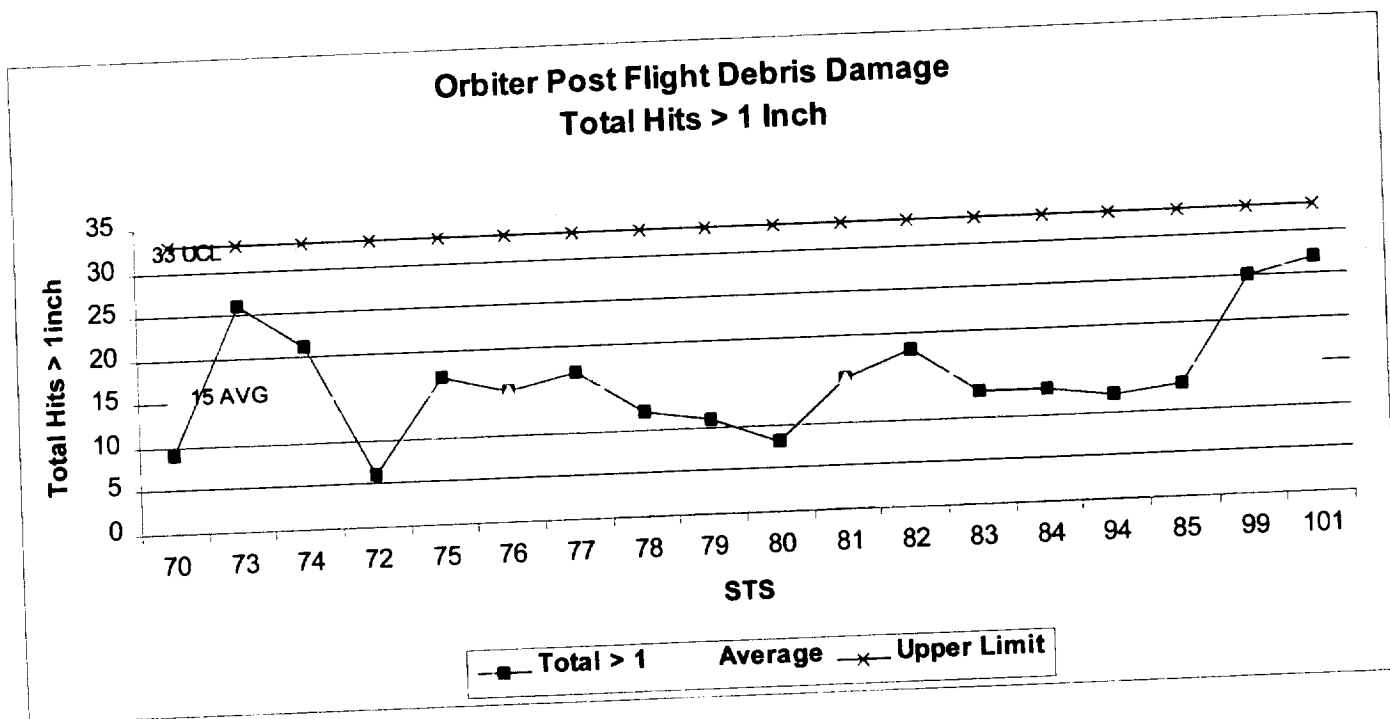




**Figure 6: Control Limits for Lower Surface Hits**







**Figure 7: Control Limits for Total Hits**



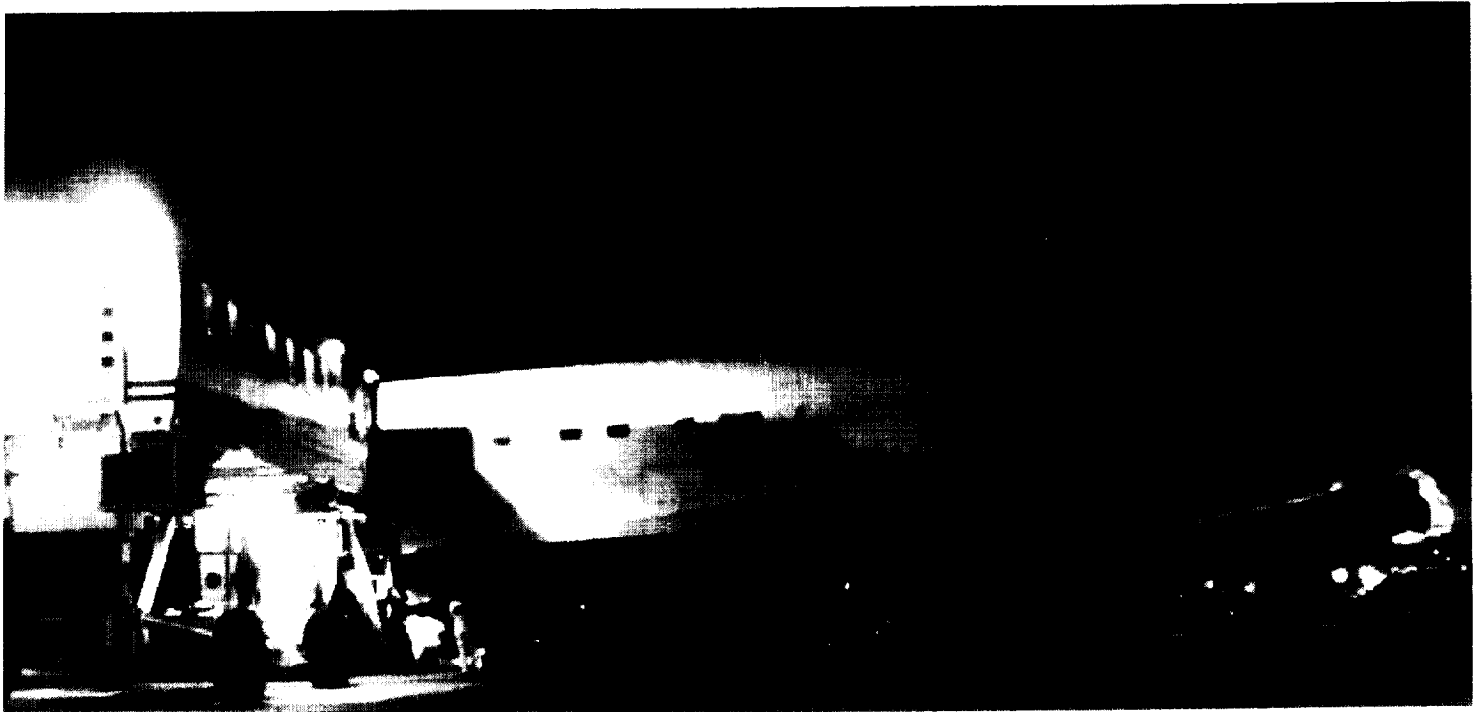
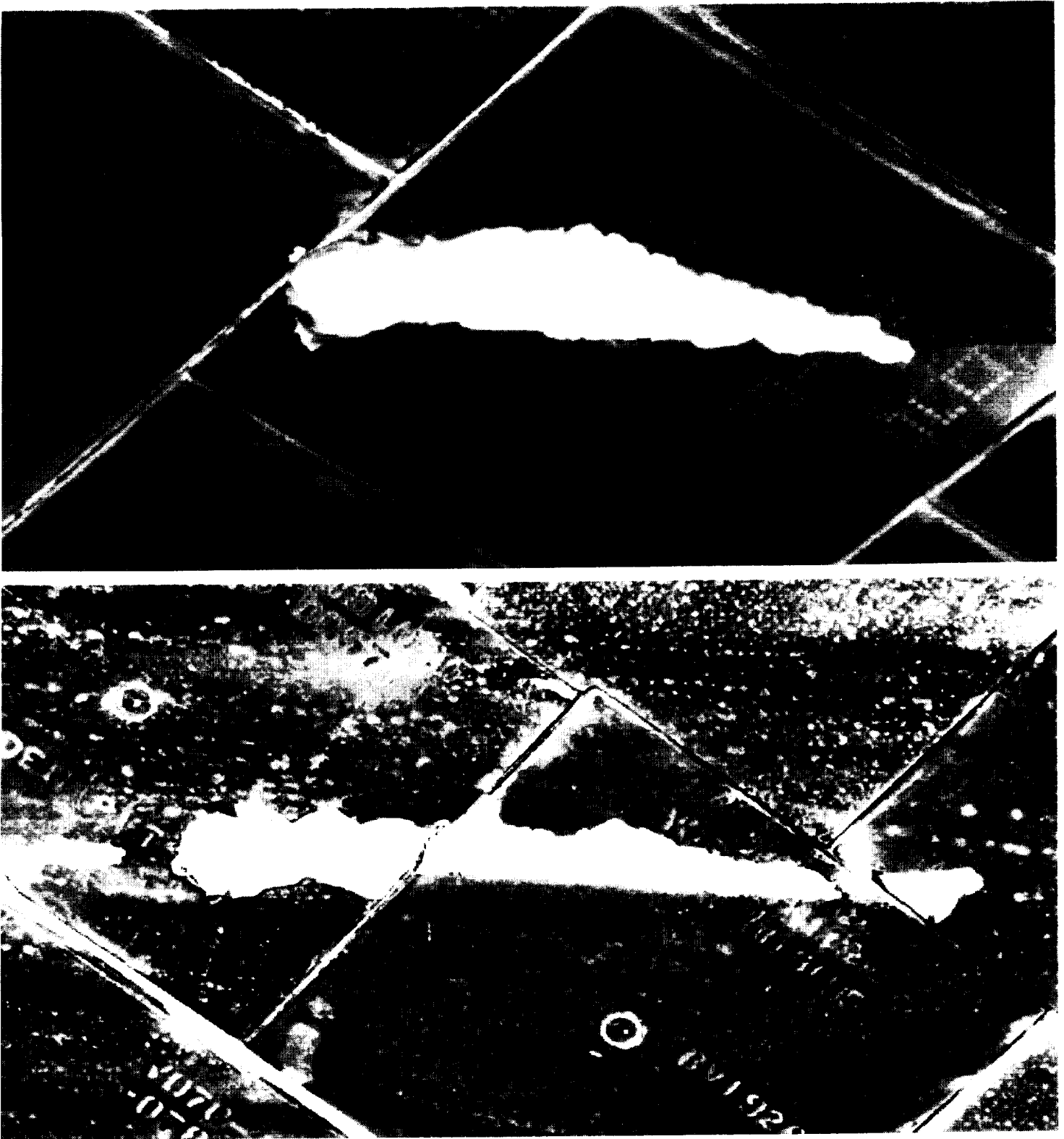


Photo 29: Overall View of Orbiter Sides





**Photo 30: Damage to Lower Surface Tiles**

Top photo shows a damage site on the lower surface of the right wing approx. 10 feet forward of the right inboard elevon hinge. This corresponded to the ice impact detected in launch films. The damage site measured 5.25-inches long by 1.5-inches wide by 0.5-inches deep, though re-entry erosion had enlarged this damage site. Bottom photo shows the largest lower surface tile damage site. It was located on the left wing immediately forward of the inboard elevon hinge and measured 8-inches long by 1.25-inches wide by 0.75-inches deep. The cause of this damage site has not been determined.



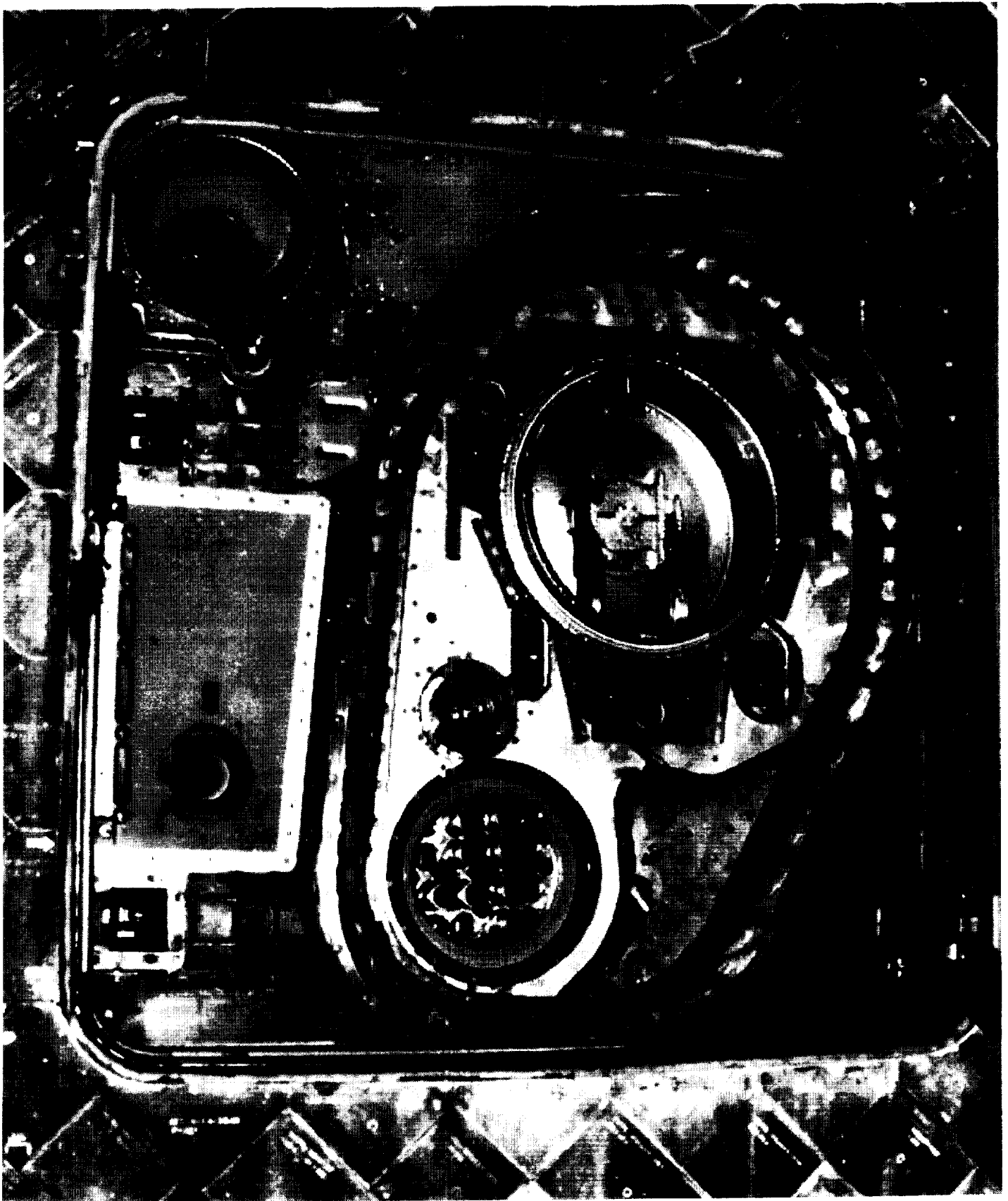


Photo 31: LO2 ET/ORB Umbilical





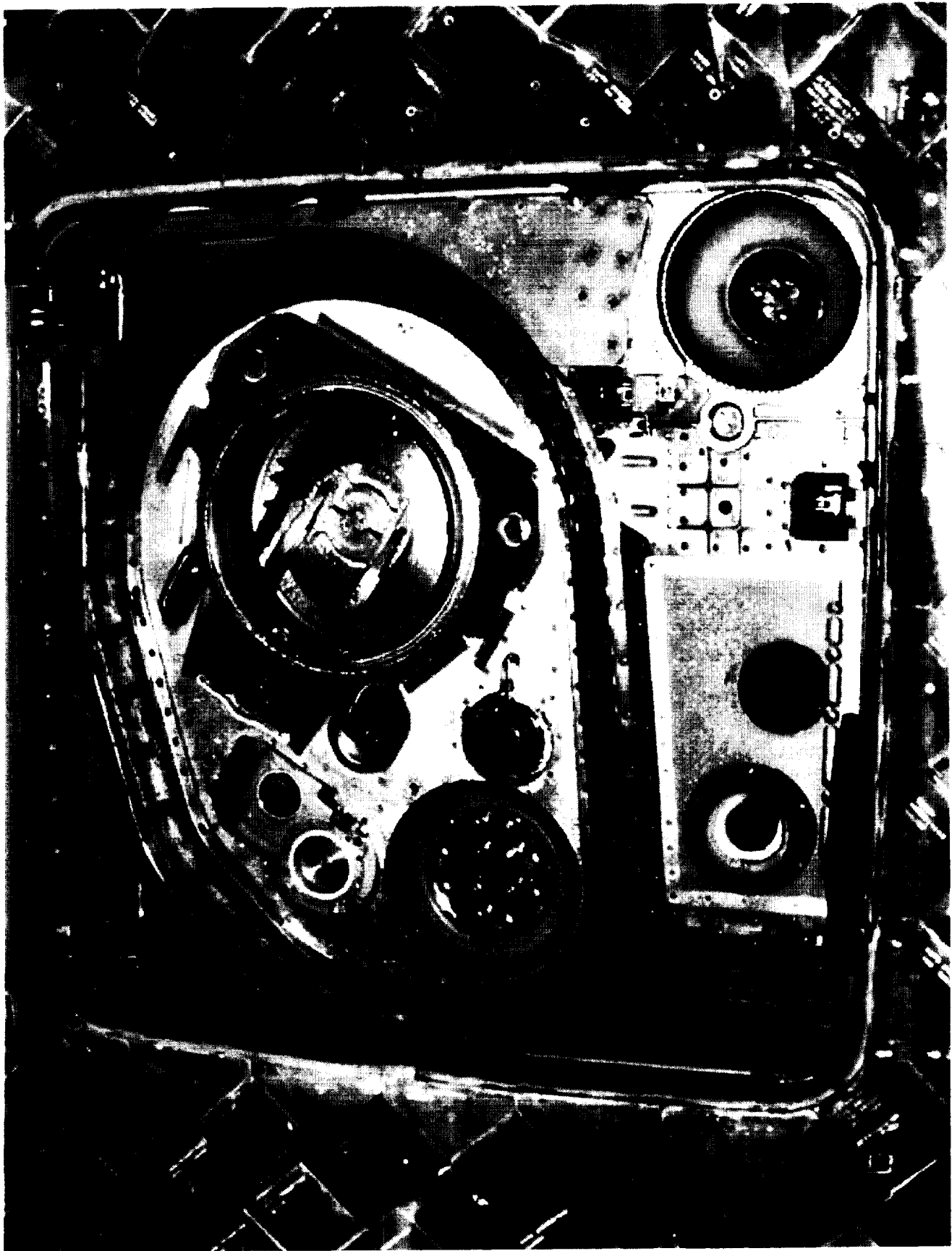
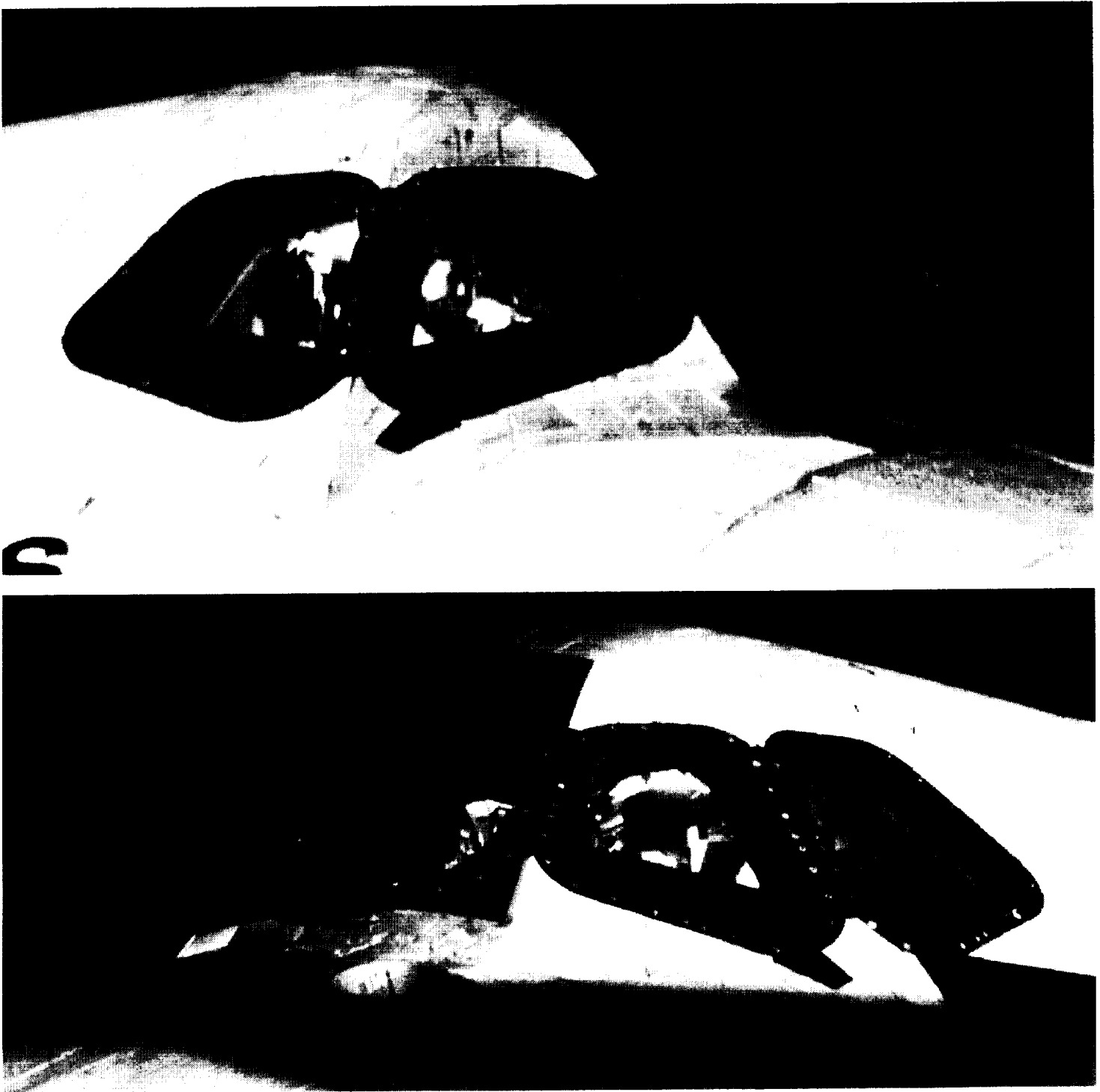


Photo 32: LH2 ET/ORB Umbilical





**Photo 33: Windows**

Damage sites on the window perimeter tiles was less than usual in quantity and size. Hazing and streaking of forward-facing Orbiter windows was moderate. The largest damage site, located in window #2 perimeter tiles, was approximately 1.5-inches long by 0.75-inches wide. This damage may be attributed to impacts from FRCS thruster paper covers and RTV adhesive.



## **APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY**

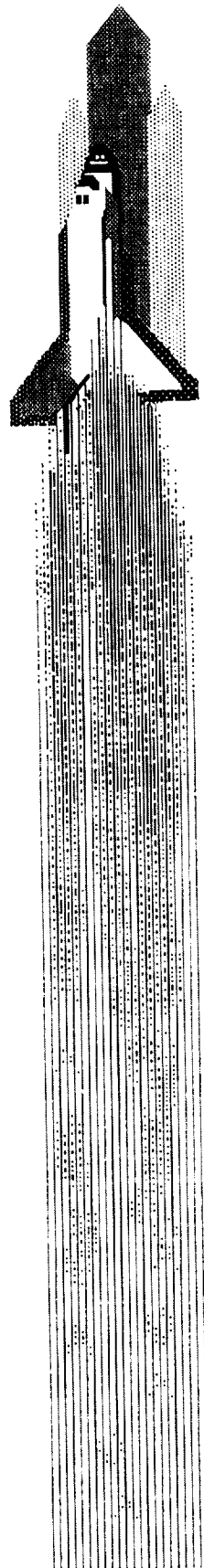




## Space Science Branch

### STS-101 Summary of Significant Events

July 6, 2000







# Space Shuttle

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## STS-101 Summary of Significant Events

Project Work Order - SN3CS

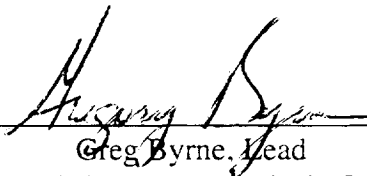
### Approved By

Lockheed Martin

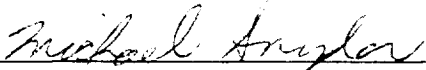
NASA



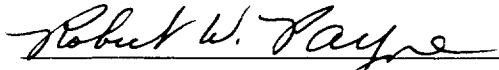
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## Table of Contents

---

1. STS-101 (OV-104): FILM/VIDEO SCREENING AND TIMING SUMMARY ..	A5
1.1 SCREENING ACTIVITIES .....	A5
1.1.1 Launch.....	A5
1.1.2 On-Orbit .....	A5
1.1.3 Landing .....	A5
1.2 LANDING EVENTS TIMING.....	A6
2. SUMMARY OF SIGNIFICANT EVENTS .....	A8
2.1 DEBRIS FROM SSME IGNITION THROUGH LIFTOFF.....	A8
2.2 DEBRIS DURING ASCENT .....	A10
2.3 MOBILE LAUNCH PLATFORM (MLP) EVENTS .....	A12
2.4 ASCENT EVENTS .....	A13
2.5 ONBOARD PHOTOGRAPHY OF THE EXTERNAL TANK (ET-92)..	A17
2.5.1 Analysis of the Umbilical Well Camera Films .....	A17
2.5.2 ET Handheld Photography .....	A22
2.5.3 ET Handheld Video .....	A25
2.6 ET THRUST PANEL VIDEO.....	A26
2.7 LANDING SINK RATE ANALYSIS .....	A28
2.8 OTHER.....	A29
2.8.1 Normal Events.....	A29
2.8.2 Normal Pad Events.....	A30

## Tables and Figures

---

Table 1.2	Landing Event Times.....	A7
Figure 2.1(A)	Ice Contacting SSME #3 Engine Bell.....	A8
Figure 2.1(B)	Orange-Colored Debris Seen after SSME Ignition.....	A9
Figure 2.1(C)	Debris Traveling Westward from the Launch Pad.....	A10
Figure 2.2(A)	Flare Seen in SSME Exhaust Plume.....	A11
Figure 2.3(A)	Orange Vapor Seen During SSME Ignition.....	A12
Table 2.3	SSME Mach Diamond Formation Times .....	A13
Figure 2.4(A)	White-colored Ring Seen inside SSME #2.....	A14
Figure 2.4(B)	STS-101 Streak Seen off Starboard Elevon.....	A15
Figure 2.4(C)	White-colored Streak at 34 Seconds MET (STS-101) and 51 Seconds MET (STS-26R).....	A15
Figure 2.4(D)	Possible Debris Contacting Right Wing .....	A16
Figure 2.5.1(A)	Detached Purge Seal on Face of LH2 Umbilical .....	A18
Figure 2.5.1(B)	Unidentified Debris.....	A19
Figure 2.5.1(C)	+Z/+Y ET Intertank .....	A20
Figure 2.5.1(D)	White-colored Object on +Y Longerons .....	A21
Figure 2.5.2(A)	Handheld ET Views .....	A23
Figure 2.5.2(B)	Handheld ET Views – Debris Seen between Legs of Forward Bipod.....	A25
Table 2.5.3	ET Tumble and Separation Rates .....	A26
Figure 2.6 (A)	ET Thrust Panel Views Prior to Separation.....	A27
Figure 2.6(B)	Divot on –Y LH2-to-intertank Flange Closeout .....	A27
Table 2.7	Main Gear Landing Sink Rate .....	A28
Figure 2.7	Main Gear Landing Sink Rate .....	A29

# **STS-101 (OV-104) Film/Video Screening and Timing Summary**

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## **1. STS-101 (OV-104): FILM/VIDEO SCREENING AND TIMING SUMMARY**

### **1.1 SCREENING ACTIVITIES**

#### **1.1.1 Launch**

The STS-101 launch of Atlantis (OV-104) from Pad 39A occurred on Friday, May 19, 2000 at approximately 140:10:11.10.003 UTC as seen on camera E9. SRB separation occurred at approximately 10:13:13.66 UTC as seen on camera ET207.

On launch day, 24 of the 24 expected videos were received and screened.

Twenty launch films were screened and a report was sent to the Shuttle Program distribution on May 23, 2000. Twenty-three additional films were received for contingency support and anomaly resolution.

A white-colored flash or streak was seen near the Orbiter right wing at approximately 34 seconds MET during the review of the STS-101 ascent videos and films. On the E224 camera film view, a white-object was (possibly) seen contacting the right wing at 34 seconds MET. A summary of similar ascent events since STS-26R was provided to the MER manager prior to landing. After the STS-101 landing, moderate tile damage was found on the undersurface of the Orbiter wing.

Other than the white-colored flash at 34 seconds MET, no anomalous events were seen.

Umbilical well cameras flew on OV-104 during STS-101. Photography of the left SRB, the LSRB/ET aft attach, and the External Tank (ET-92) aft dome was acquired using umbilical well camera films during SRB separation. Umbilical well camera photography of the External Tank (ET) was also acquired during ET separation and handheld still photography/video of the ET was acquired following separation.

Video (acquired from cameras mounted on the SRB forward skirts) of the External Tank's +Y and -Y thrust panels was acquired during ascent on STS-101.

#### **1.1.2 On-Orbit**

No unplanned on-orbit Shuttle analysis support was requested. Pre-planned real-time analysis support was provided to the ISS AF-2A.2A Space Station photographic and television external survey. The Space Station image analysis support will be documented in the AF-2A.2A Imagery Overview Report. (No post-mission report was requested.)

#### **1.1.3 Landing**

Atlantis made a night landing on runway 15 at the KSC Shuttle Landing Facility on May 28, 2000 at 06:20:17.96 UTC. Ten videos and ten films were received.

## **STS-101 (OV-104) Film/Video Screening and Timing Summary**

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The landing touchdown appeared normal. No anomalous events were seen during the Orbiter approach, landing, and landing roll-out.

Post landing, a sink rate analysis of the STS-101 main landing gear was performed for the main gear touchdown.

The drag chute deploy sequence appeared normal on the landing imagery. Flames from the APU vent located at the forward edge of the base of the vertical stabilizer were seen during the landing roll out and after wheel stop. Flames from the APU during landing have occurred on previous missions.

According to the pre-mission agreement, the STS-101 landing films were not screened due to budgetary constraints.

### **1.2 LANDING EVENTS TIMING**

The time codes from videos were used to identify specific events during the screening process. The landing event times are provided in Table 1.2.

## **STS-101 (OV-104) Film/Video Screening and Timing Summary**

### **STS-101 Landing and Drag Chute Event Times from Video**

<b>Event Description</b>	<b>Time (UTC)</b>	<b>Camera</b>
Main gear door opening	No Timing	EL17IR
Right main gear inboard tire touchdown	150:06:20:17.96	SLF N
Left main gear tire touchdown	150:06:20:17.99	SLF N
Drag chute initiation	150:06:20:21.99	KTV15L
Pilot chute at full inflation	150:06:20:22.95	KTV33L
Bag release	150:06:20:23.52	KTV33L
Drag chute inflation in reefed configuration	150:06:20:24.62	KTV33L
Drag chute inflation in disreefed configuration	150:06:20:28.56	KTV33L
Nose gear tire touchdown	150:06:20:29.26	KTV33L
Drag chute release	~150:06:20:57.0	KTV33L
Wheel stop	~150:06:21:13.7	KTV33L

Note: The symbol ~ means that the event was not clearly seen because of the limited light available during the night landing and the event time shown is approximate.

Table 1.2 Landing Event Times





## Summary of Significant Events

---

### 2. SUMMARY OF SIGNIFICANT EVENTS

#### 2.1 DEBRIS FROM SSME IGNITION THROUGH LIFTOFF

Multiple pieces of ice debris and vapors were seen falling from the ET/Orbiter umbilicals along the -Z side of the body flap during SSME ignition.

Vapor and ice debris were seen falling from the ET side of the 4-inch LH2 recirculation line and white-colored debris (probably ice) was seen falling from an unidentified area forward of the -Y aft ET attach (10:11:06.210 UTC). None of the debris was seen to contact the vehicle. (Cameras OTV009, OTV054, E1, E4, E5, E17, E19, E31, E34, E36)

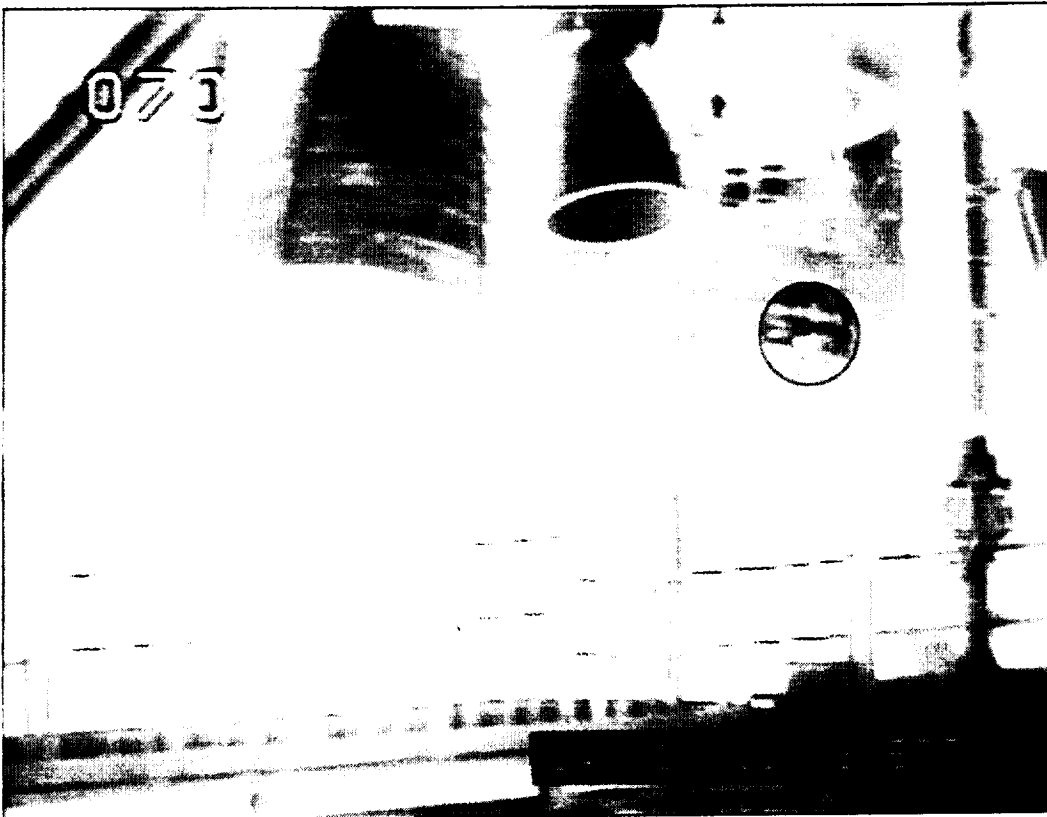


Figure 2.1(A) Ice Contacting SSME #3 Engine Bell

A large, single piece of white-colored debris (ice) from the LO2 TSM T-0 disconnect fell aft and contacted the SSME #3 engine bell at the number 8 hatband forward of the SSME #3 rim prior to the SSME Mach diamond formation (10:11:06.438 UTC). See Figure 2.1(A). A second piece of debris contacted the SSME #3 engine bell forward of the rim during SSME ignition (10:11:06.636 UTC). A large, white-colored, vaporous cloud from the LO2 TSM T-0 disconnect was seen near SSME #3 at 10:11:10.9 UTC. No damage to the SSME #3 engine bell was detected. (Cameras OTV051, OTV070, OTV071, E19, E76)



## Summary of Significant Events

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On camera E1, two light-colored pieces of debris were seen being ejected from the flame trench and arc forward toward the main engines during SSME ignition. On camera E19 (possibly the same event), a single, irregular-shaped, dark-colored piece of debris was seen near SSME #3 during SSME ignition. (10:11:06.681 UTC). On camera E5, two pieces of light-colored debris were seen being ejected from the flame trench and traveling in an upward direction near the -Z side of the body flap prior to liftoff (10:11:08.890 UTC). SRB flame trench debris was seen moving northward away from the vehicle at liftoff (10:11:11.432 UTC). This debris was not seen to contact the launch vehicle. (Cameras E1, E4, E5, E19, E36, E52)

White-colored vapor (probably condensation) was seen to originate from the +Y ET vertical strut attach area during SSME ignition. A single piece of ice debris fell aft and contacted the forward surface of the ET +Y vertical strut (10:11:06.987 UTC). Pieces of light-colored debris were seen falling from the -Y ET vertical strut attach during SSME ignition (10:11:05.54, 10:11:06.210 UTC). No damage was detected. (Cameras OTV054, OTV063, E5, E31)



Figure 2.1(B) Orange-Colored Debris Seen after SSME Ignition

A single, orange-colored, linear-shaped, flexible appearing object (possibly a piece of umbilical purge barrier tape) fell aft along the -Z side of the body flap after SSME ignition (10:11:08.876 UTC). See Figure 2.1(B). (Camera E18)

A red-colored, rectangular-shaped piece of unidentified debris (possible RCS paper) was seen falling aft near the base of SSME #2 and SSME #3 during SSME ignition (10:11:06.311 UTC). (Camera E19)





Figure 2.1(C) Debris Traveling Westward from the Launch Pad

A large light-colored rectangular-shaped piece of debris was seen during liftoff traveling westward from the launch pad. See Figure 2.1(C). KSC reported that the debris might be a panel from the RSS. This debris did not appear to be in close proximity to the launch vehicle. (Camera KTV21A)

A single light-colored piece of debris was seen moving from the -Y side of the launch vehicle and fell aft near the LSRB during liftoff (10:11:12.476 UTC). The debris was not seen to contact the vehicle. (Camera E4)

## 2.2 DEBRIS DURING ASCENT

Debris typical of that seen on previous missions were seen aft of the launch vehicle during ascent:

Multiple pieces of debris (umbilical ice and RCS paper debris too numerous to count) were seen falling aft of the launch vehicle during ascent. Orange-colored ET/Orbiter umbilical purge barrier material debris were seen aft of the body flap (10:11:25.9 and 10:11:40.6 UTC). A spray of light-colored debris (probably forward RCS paper) was seen near the trailing edge of the vertical stabilizer at 10:11:26.446 UTC. Forward RCS



## Summary of Significant Events

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paper debris, first seen near the right OMS pod, fell aft producing a flare in the SSME exhaust plume.



Figure 2.2(A) Flare Seen in SSME Exhaust Plume

A piece of RCS paper debris was seen falling from a region near the left RCS stinger, moving across the +Z side of SSME #1, past the -X side of SSME #2, and traveling aft into the SSME exhaust plume resulting in a large orange-colored debris-induced flare (10:12:03.2 UTC). See Figure 2.2(A). Other smaller flares in the SSME exhaust plume (probably debris induced) were also seen during ascent (10:11:46.4, 10:11:54.2 UTC). Furthermore, debris was seen near the SRB exhaust plume during ascent (10:11:11.35, 10:11:45.2, 10:12:13.9, 10:12:23.5, 10:12:24.2, 10:12:26.9 UTC). (Cameras KTV2, KTV5, KTV4A, ET207, ET212, ET213, E52, E207, E212, E222, E223, E224)





### 2.3 MOBILE LAUNCH PLATFORM (MLP) EVENTS

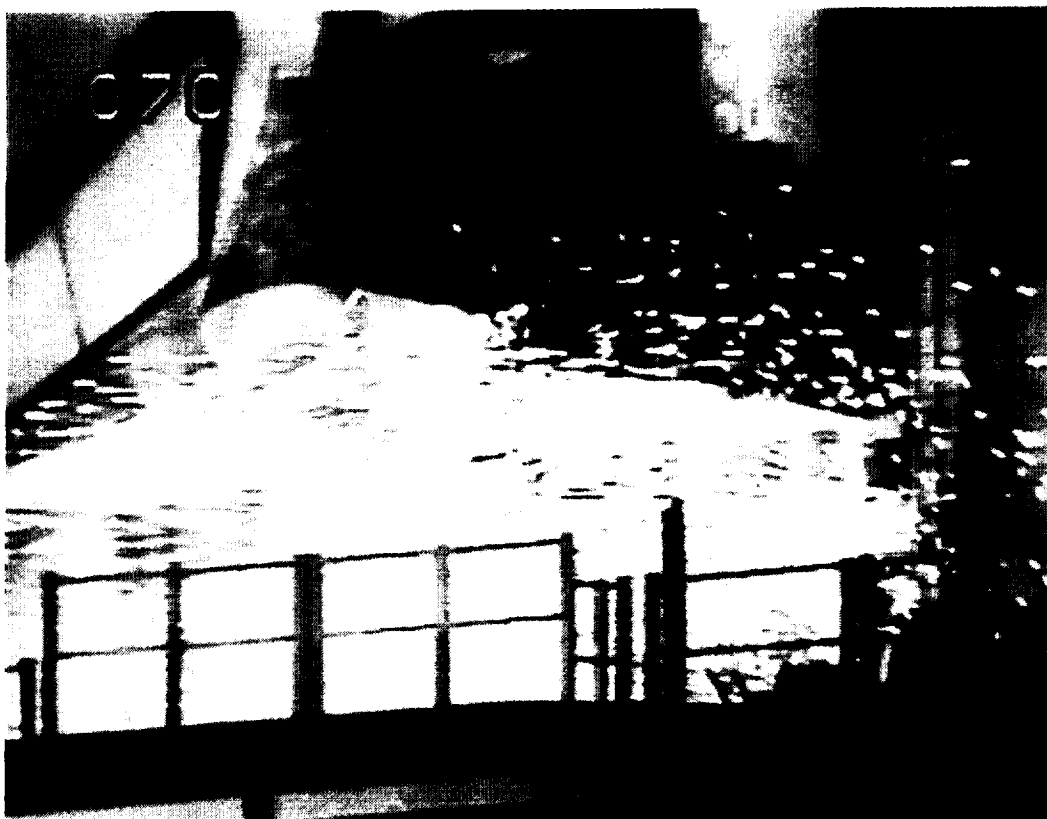


Figure 2.3(A) Orange Vapor Seen During SSME Ignition

Extensive orange vapor (possibly free burning hydrogen) was seen forward of the SSME rims, contacting the drag chute door, and extending forward along the base of the vertical stabilizer during SSME ignition (10:11:04.7 UTC). See Figure 2.3(A). Orange vapor forward of the SSME rims has been seen on previous mission films and videos. However, the orange vapor seen on STS-101 was more apparent than the vapors seen on most previous missions. (Cameras OTV051, OTV070, E1, E2, E5, E17, E18, E19, E20, E63, E76)

The SSME ignition appeared normal on the high-speed engineering films and the SSME Mach diamonds appeared to form in the expected sequence (3, 2, 1). The times for the Mach diamond formation given in Table 2.3 are from camera film E19.



## Summary of Significant Events

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SSME	TIME (UTC)
SSME #3	10:11:06.693 UTC
SSME #2	10:11:06.830 UTC
SSME #1	10:11:07.066 UTC

Table 2.3 SSME Mach Diamond Formation Times

A faint, light-colored flash was seen extending aft from the SSME #2 nozzle rim prior to liftoff (10:11:07.784 UTC). (Camera E19)

Two small areas of tile surface coating material erosion were seen during SSME ignition on the base heat shield near the base of the right RCS stinger (11:10:05.438 UTC). At approximately the same time, three small areas of tile surface coating material erosion were seen on the base heat shield inboard of the left downward firing RCS thrusters, and on the base heat shield outboard of SSME #2. Erosion of the tile surface coating material is typically seen on the launch imagery. (Cameras E17, E18)

No indication of holddown post (HDP) stud hang-ups were seen and no debris was seen falling from the HDP stud holes.

Post landing, engineers noted an unusually high frequency response in the strain gage data acquired during launch from RSRB holddown posts M-2 and M-4. This high frequency response was declared an in-flight anomaly (IFA number STS-101-1-01) per Program Requirements Control Board (PRCB) S062139, on June 8, 2000. The RSRB holddown post films were reviewed with engineers from Space Shuttle Systems Integration for unusual motions or debris that might have been associated with the high frequency strain gage readings. However, no anomalous conditions were noted on the films.

PIC firing was timed at 10:11:10.003 UTC on HDP M-1, camera film E9.

## 2.4 ASCENT EVENTS

The R2R and R3R paper covers on the side firing RCS thrusters did not tear away prior to or during early lift off as is typically seen. Also, the paper covers on the port RCS aft firing thrusters did not tear away. KSC reported that, although unusual, this is not an anomalous event. (Cameras E2, E5, E18)



## Summary of Significant Events

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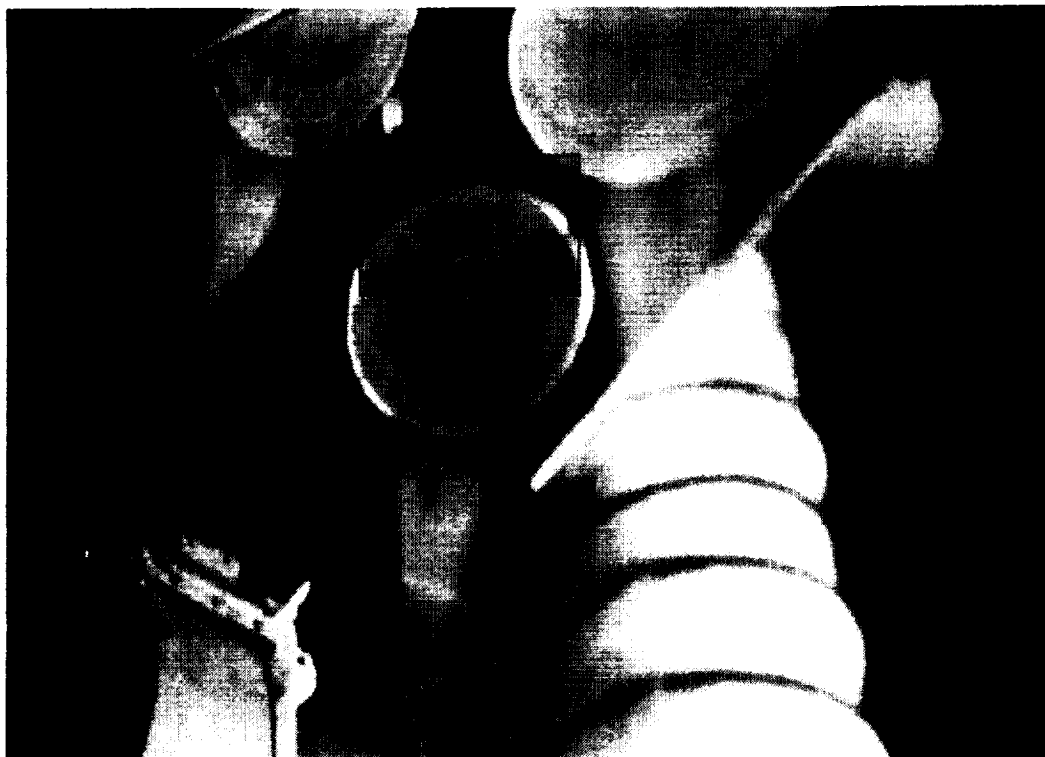


Figure 2.4(A) White-colored Ring Seen inside SSME #2

A white-colored ring was visible on the hot wall inside of the SSME #2 nozzle at liftoff (10:11:11.732 UTC) and during ascent (10:12:22.5 UTC). See Figure 2.4(A). MSFC reported that the SSME #2 hot wall appeared normal on the camera E19 liftoff view. No follow-up action was requested. (Cameras E19, E207, ET207)

On STS-101 ascent, a long white-colored vaporous streak was seen trailing from the right inboard elevon after the roll maneuver at approximately 34 seconds MET (10:11:44.15 UTC). See Figure 2.4(B). Figure 2.4(C) contains a comparison between a similar, but more extensive, streak seen on STS-26R with the streak seen on STS-101. (The streak on STS-26R occurred at approximately 51 seconds MET.) Prior to the STS-101 landing, the MER manager was provided with a summary of the previous Space Shuttle flights with known launch events that could possibly be associated with Orbiter tile damage.





Figure 2.4(B) STS-101 Streak Seen off Starboard Elevon

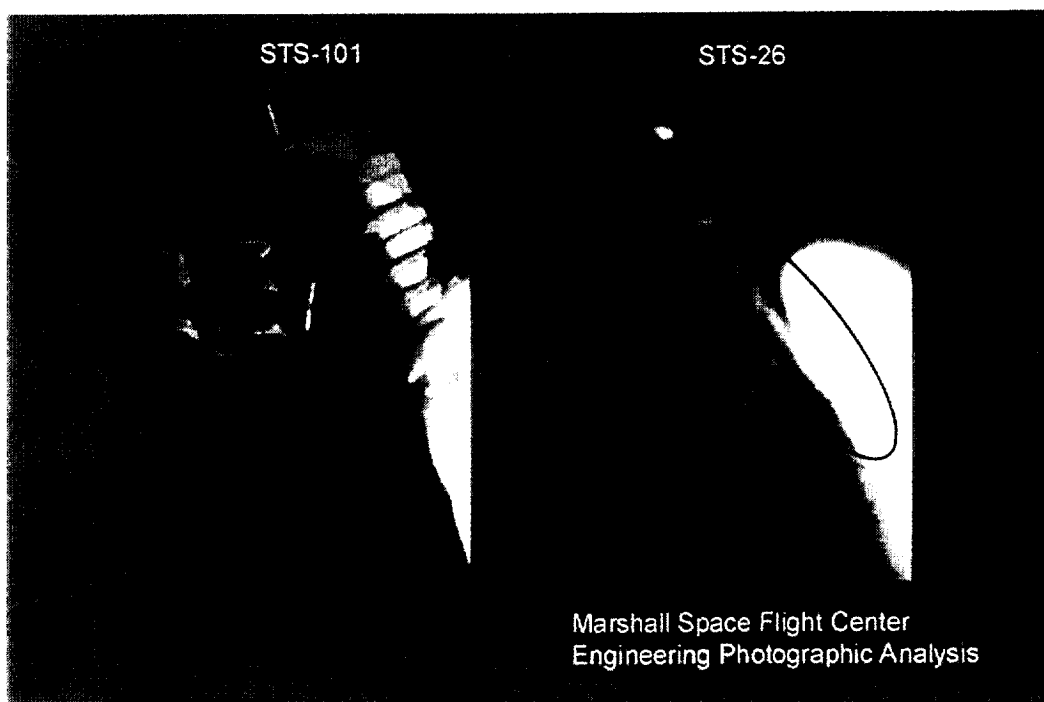


Figure 2.4(C) White-colored Streak at 34 Seconds MET (STS-101)  
and 51 Seconds MET (STS-26R)





## Summary of Significant Events

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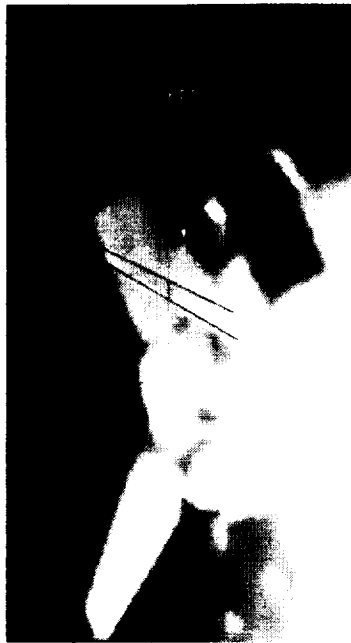


Figure 2.4(D) Possible Debris Contacting Right Wing

On STS-101 camera film E224 (Figure 2.4(D)), a white-colored object appeared to (possibly) contact the undersurface of the right wing (outlined in red) immediately prior to the time that the streak was visible on the camera ET207 view shown in Figure 2.4(B). (10:11:44.109 UTC). (Cameras ET207, E207, E224)

Post landing inspections confirmed that tile damage to the underside of the right wing, previously suspected because of the imagery screening, had occurred. However KSC reported that this damage was not a significant concern. The impact site was located about 10 feet in front of the right inboard elevon and measured 5.25-inches long, 1.5-inches wide and 0.5-inch deep. (As a comparison, STS-26R tile damage measured during the post landing inspection was 18 x 6 inches in area and extended 1.5 inches into the upper surface of the right wing). On STS-101, there was no indication of structural damage.

A bright flash from the planned OMS assist burn was seen at the aft end of the launch vehicle approximately eleven seconds after SRB separation (10:13:24.1 UTC). (Cameras ET204, ET207, ET208, E212, KTV13, E212)

White-colored vapor (probably water) was seen streaming from the drain hole at the mid-level of the trailing edge of the rudder speed brake during liftoff and early ascent. This event has been seen on previous missions. (Camera E52)

Body flap motion was seen during ascent with the amplitude and frequency of the motion appearing similar to that seen on previous mission imagery. No follow-up action was requested. (Camera E207)



## Summary of Significant Events

### **2.5 ONBOARD PHOTOGRAPHY OF THE EXTERNAL TANK (ET-102)**

#### **2.5.1 Analysis of the Umbilical Well Camera Films**

##### 16mm Umbilical Well Camera Films

The FL101 (5mm wide angle lens) 16mm umbilical film was not received and was reported by KSC to be a no run. The FL102 (10mm lens) 16mm umbilical well film was received, however, back lighting from the early morning Sun degraded the film quality. Timing data was present on camera film (FL102).

The LSRB separation appeared normal on the 16mm umbilical well camera film. Numerous light-colored pieces of debris (insulation), and dark debris (charred insulation) were seen throughout the SRB separation film sequence. Typical ablation and charring of the ET/Orbiter LH2 umbilical electric cable tray and the aft surface of the -Y upper strut fairing were seen prior to SRB separation. Numerous irregularly shaped pieces of debris (charred insulation) were noted near the base of the LSRB electric cable tray prior to SRB separation. Pieces of TPS were seen detaching from the aft surface of the horizontal section of the -Y ET vertical strut and several small pieces of dark-colored debris were seen near the aft LSRB/ET attach at SRB separation. The amount of ablation of the TPS on the aft dome was typical of previous flights. The SRB nose caps were not seen because of the narrow angle of the 10mm lens and dark shadows.

The ET separation from the Orbiter appeared normal. Typical vapor and multiple light-colored pieces of debris (frozen hydrogen) were seen almost continuously before, during, and after the umbilical separation.



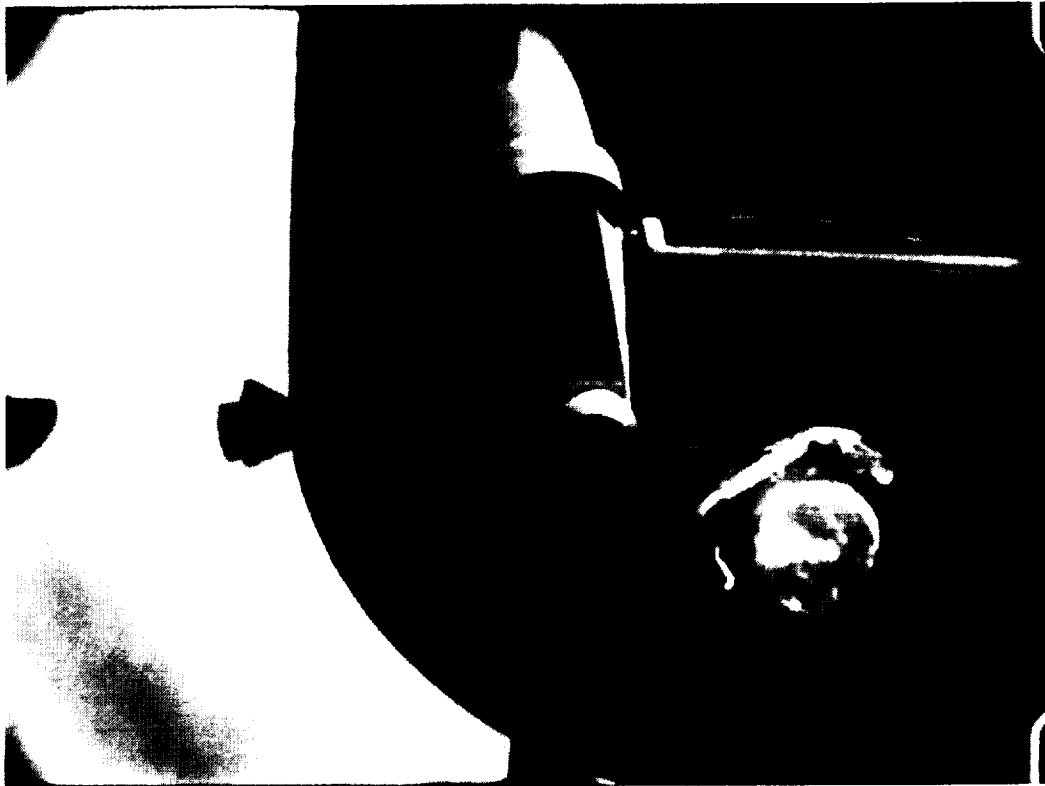


Figure 2.5.1(A) Detached Purge Seal on Face of LH2 Umbilical

Most of the face of the ET/Orbiter LH2 umbilical was obscured by shadows during the separation of the ET from the Orbiter. However, a forward outboard portion (~9 o'clock position on the face of the LH2 umbilical) of the white-colored purge seal was seen to be partially detached and extending outward toward the camera (+Z direction). See Figure 2.5.1(A). As typically seen on previous missions, frozen hydrogen was visible on the orifice of the LH2 17 inch connect and near the 1 o'clock position of the LH2 umbilical and the -Y end of the ET cross beam. The red-colored purge seal on the EO-2 ball joint fitting appeared to be in place.

The +Z and -Y aspects of the LH2 tank, intertank, and Ojive were in shadow and too dark for analysis. The -Y ET thrust panel was in shadow and too dark for analysis. However, the portions of the +Z/+Y LH2 tank, intertank, and Ojive (including the LO2 feedline, press lines, cable trays, and ramps) that were visible appeared in good condition.





Figure 2.5.1(B) Unidentified Debris

On frames 7819 through 7900, a circular-shaped debris object was seen tumbling aft along the left side of the field of view. See Figure 2.5.1(B). The object appeared close to the camera and had a large inner diameter. KSC reported that the object might be an O-ring rather than a washer.

### 35mm Umbilical Well Camera Film

The +X translation maneuver was performed on STS-101 to facilitate the imaging of the ET with the umbilical well cameras. However MOD reported that the +X maneuver was started late resulting in the nose of the ET not being recorded on the 35mm umbilical well camera film (roll 404). Sixty frames imaging the ET were acquired. The film quality is excellent. However, the left side of the view (+Z / -Y axis of the ET) is obscured by shadow and is too dark for analysis. Frames 54 through 60 were camera run-down frames (typically seen) and have an orange-colored tone rather than normal color tones.

Based on the screening of the close-up 35mm umbilical well camera film, the visible portions of the ET appeared to be in good condition after the separation from the Orbiter.

The un-shadowed, visible portion of the +Z/+Y LH2 tank TPS appeared to be in excellent condition. A possible area of minor LH2 tank TPS erosion was seen in the +Y direction from the +Y longeron at approximately station XT-1900 that was not visible on the pre-launch closeout photography. However, the color and tone of these marks is similar to





## Summary of Significant Events

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older pre-launch repair marks indicating that no additional TPS coating was lost during ascent.

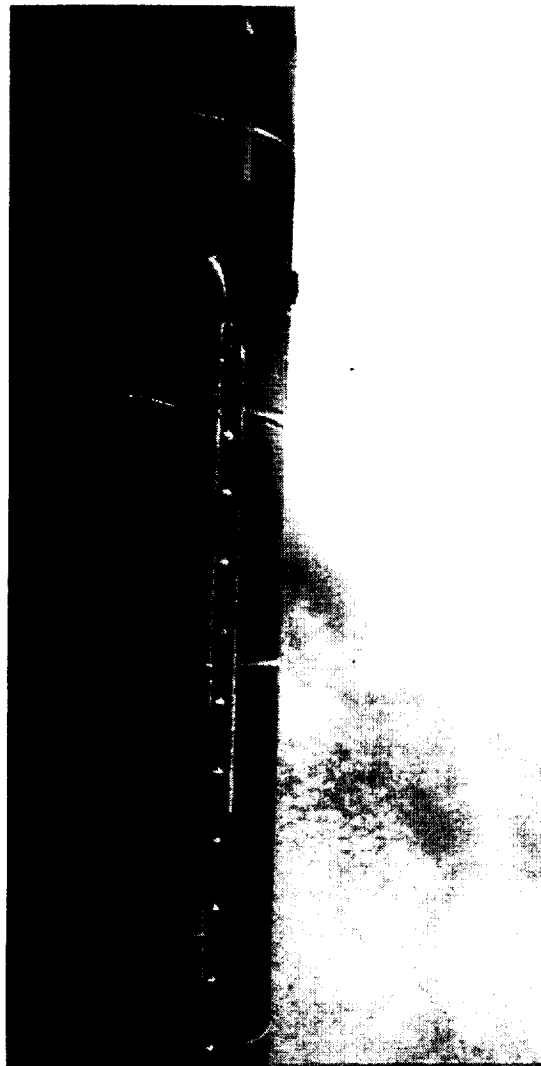


Figure 2.5.1(C) +Z/+Y ET Intertank

The visible portion of the +Z/+Y ET Thrust Panel appeared in excellent condition. No divots were noted on the rib heads of the +Y ET thrust panel TPS. As expected, the left (-Y) SRB thrust panel was not imaged on this film.

The LH2 tank-to-intertank flange closeout between the legs of the forward ET/Orbiter attach bipod could not be seen because of the dark shadow. (A possible divot was seen at this location on the fully illuminated handheld photography).



## Summary of Significant Events

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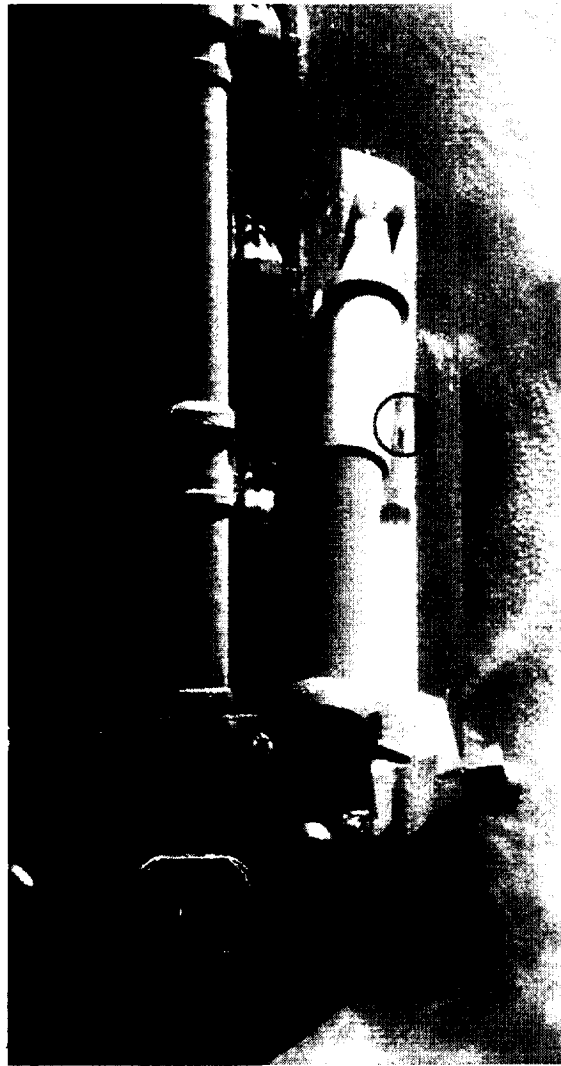


Figure 2.5.1(D) White-colored Object on +Y Longeron

A small, square-shaped, white-colored object that appears to be ice / frost or possibly a piece of up-lifted TPS was seen near the mid level of the +Y longeron at approximately station XT-1980. See Figure 2.5.1(D). KSC reported that a hairline crack was noted on this area of the +Y longeron during cryo-loading.

A small, square-shaped, white-colored mark (possible shallow divot) was seen on the -Y end of the +Y vertical strut at approximately station XT-2030.

Minor TPS chipping and very small divots (typical of previous missions) were seen on the aft LO2 feedline flanges and on the aft bracket over the press lines. Small, shallow areas of TPS erosion and divoting were visible on the aft flange of the +Y ET/Orbiter thrust strut. Typical ablation and divoting of the TPS on the vertical section of the +Y electric cable tray adjacent to the LO2 umbilical were detected. The ET aft dome was obscured by shadow.



## **Summary of Significant Events**

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The face of the LO2 umbilical carrier plate, although mostly in shadow, appeared to be in excellent condition (no indication of damaged or missing lightning contact strips was detected).

The visible portion of the red-colored purge seal on the EO-3 ball joint fitting appeared to be in place.

### **2.5.2 ET Handheld Photography**

The STS-101 handheld pictures of the External Tank (ET-102) are excellent in quality. The ET was fully illuminated with very little shadowing. Timing data is present on the film with the first picture being taken at 16:35 (minutes:seconds) MET. The distance of the ET from the Orbiter was calculated to be approximately 2.3 km on the first photographic frame acquired. At this distance, objects (damage) smaller than seven to eight inches in size are not detectable. The separation velocity of the ET from the Orbiter was estimated to be 7.4 m/sec.

The astronauts performed a manual pitch maneuver from the heads-up position to bring the ET into view in the Orbiter overhead windows for the handheld photography. (STS-101 was the tenth flight using the roll-to-heads-up maneuver).

Thirty-five images of the ET were acquired using the handheld 35mm Nikon F5 camera with a 400mm lens (roll 382). Views of the nose, the aft dome, the side of the ET facing the Orbiter (+Z), and both limbs (+/- Y sides) of the ET were obtained. The far side (-Z) of the ET was not imaged.



## Summary of Significant Events

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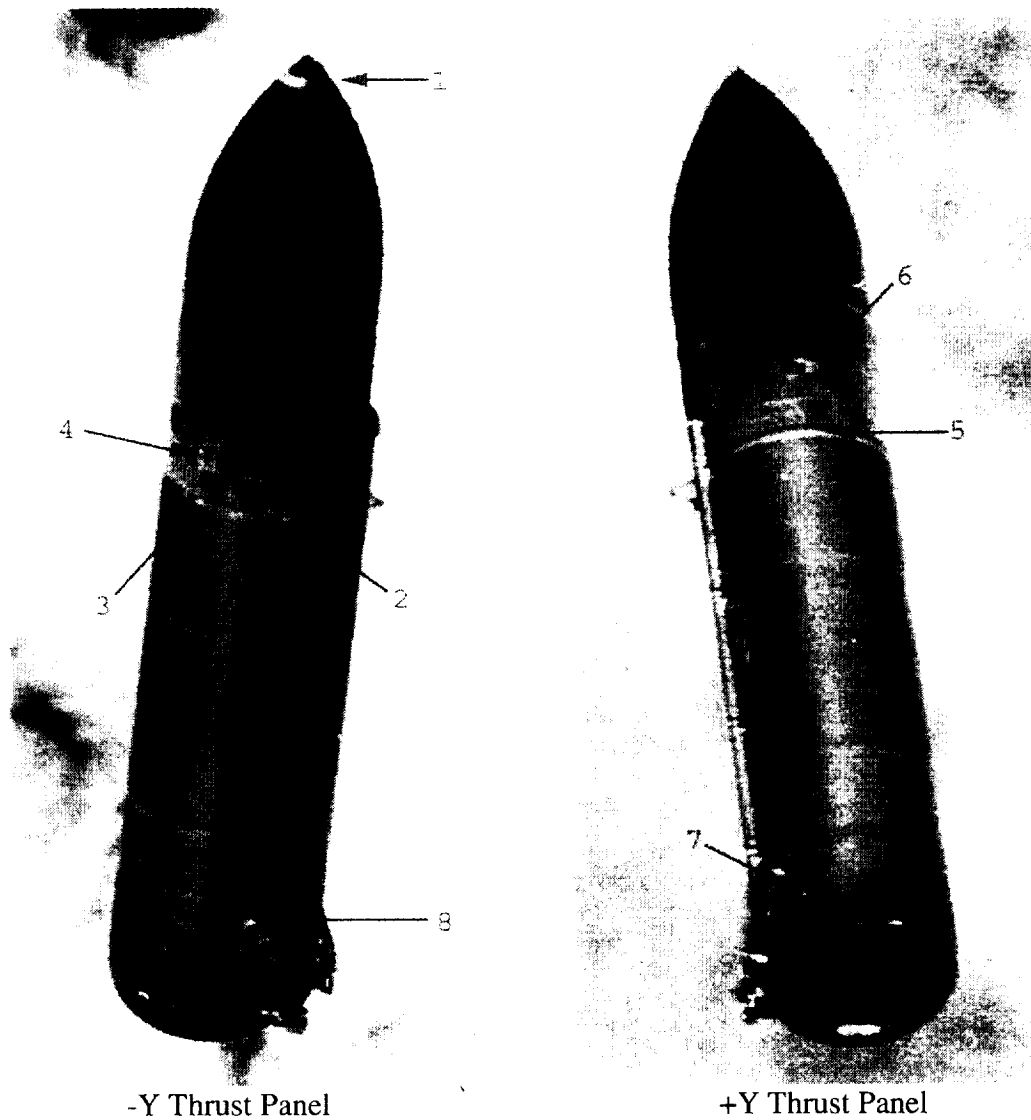


Figure 2.5.2(A) Handheld ET Views

The normal SRB separation burn scars and aero-heating marks were noted on the intertank and nose TPS of the ET. See Figure 2.5.2(A). In addition, the following items were noted:

- A band of eroded TPS (and possible divots) was seen just aft of the ET nose cap. (Figure 2.5.2(A) annotation #1)
- Two light-colored marks (divots), approximately 9-inches in diameter, are visible in the direction of the left (-Y) limb of the ET on the LH2 tank-to-intertank flange closeout between the bipod and the -Y thrust panel. (Figure 2.5.2(A) annotation #2)
- A light-colored mark (divot), approximately 9-inches in size was seen near the LH2 tank-to-intertank flange at the aft -Y corner of the -Y thrust panel. (Figure 2.5.2(A)





## **Summary of Significant Events**

annotation #3) (On the LSRB thrust panel video, this divot appeared to be in the LH2 tank TPS adjacent to the flange close-out.)

- Three large appearing light-colored areas were noted on the -Y thrust panel in the -Y direction from the LSRB forward attach fitting. (On the LSRB thrust panel video, there is an indication of possible small divots on several rib heads in one of these three areas that could be seen during SRB separation.) (Figure 2.5.2(A) annotation #4)
- Two light-colored marks were detected on the +Y LH2 tank-to-intertank flange close out aft of the forward RSRB attach fitting. (Figure 2.5.2(A) annotation #5) This portion of the LH2 tank-to-intertank flange close out was imaged on the close-up RSRB thrust panel video during ET separation. However, no indication of TPS erosion or divots was seen on the close up video.
- Three light-colored areas were detected on the +Y thrust panel in the +Y direction from the RSRB forward attach fitting. These light-colored areas may be caused by areas of TPS erosion or clusters of divots too small to resolve on the handheld film. (Figure 2.5.2(A) annotation #6)
- A light-colored mark (possible divot) was seen on the +Y longeron (Figure 2.5.2(A) annotation #7). This may be the white-colored object visible on the 35mm umbilical well camera film circled on Figure 2.5.1(D).
- A light-colored mark (possible divot) was seen on the forward left corner of the -Y longeron. (Figure 2.5.2(A) annotation #8)

The area of divots seen in the unvented area aft of station 1013 on the RSRB thrust panel seen on the higher resolution, close-up, SRB thrust panel video was not detected on the handheld photography. (These divots were estimated to be less than 5-inches in size on the video which is below the estimated resolution seen on the handheld film.)





Figure 2.5.2(B) Handheld ET Views – Debris Seen between Legs of Forward Bipod

- A light-colored mark (divot), approximately 8 to 9-inches in size, is visible on the LH2 tank-to-intertank flange closeout between the legs of the forward bipod. (Figure 2.5.2(B))

(Venting from the ET intertank region was not seen on the STS-101 handheld film. However, venting was seen on the handheld video).

### 2.5.3 ET Handheld Video

The crew handheld video of the ET was acquired on STS-101. However there was no timing data on the video. Venting from the ET intertank region was seen on the crew handheld video.

Table 2.5.3 contains a comparison of the averaged tumble rate(end-to-end rotation of the ET about its center of mass) measurements for the current and eight previous Space Shuttle missions.



## Summary of Significant Events

MISSION	Tumble Rate (deg/sec)	Separation Rate (m/sec)	MET (mm:ss)	Venting
STS-87	11	--	17:23 - 18:08	Yes
STS-89	12	--	31:42 - 35:27	Yes
STS-90	3	--	14:30*	Yes
STS-91	11	--	16:29 - 18:46	Yes
STS-95	< 1	5.5 (prior to venting)	13:40 - 20:50	Yes
STS-88	2	6.2	15:39 - 22:44	No
STS-96	1.3	6.5	13:21 - 18:21	No
STS-93	14.7	Not Determined	28:56 - 32:56	No
STS-103	--	Not Determined	--	--
STS-99	--	5.8	21:14 - 22:31	Yes
STS-101	5.8 (pre-vent) 6.9 (post-vent)	7.4	No Timing	Yes

Only the first four frames had timing data (on STS-90 photography). Relative time from video was used to determine the STS-90 tumble rate.

Table 2.5.3 ET Tumble and Separation Rates

Venting from the ET intertank region has been seen on six (recently flown) previous missions (STS-87, STS-89, STS-90, STS-91, STS-95, STS-99).

## 2.6 ET THRUST PANEL VIDEO

The left and right SRB thrust videos are excellent in quality with good exposure and focus. As on the previous mission thrust panel video, the divots began to form after approximately 100 seconds MET. As before, there were smaller and fewer divots in the vented areas of the thrust panels compared to the non vented areas. Most of the divots were shallow and less than 0.5-inches in size. No primed substrate was detected. There was a greater number of divots visible on the right SRB thrust panel compared to the left SRB thrust panel.



## Summary of Significant Events

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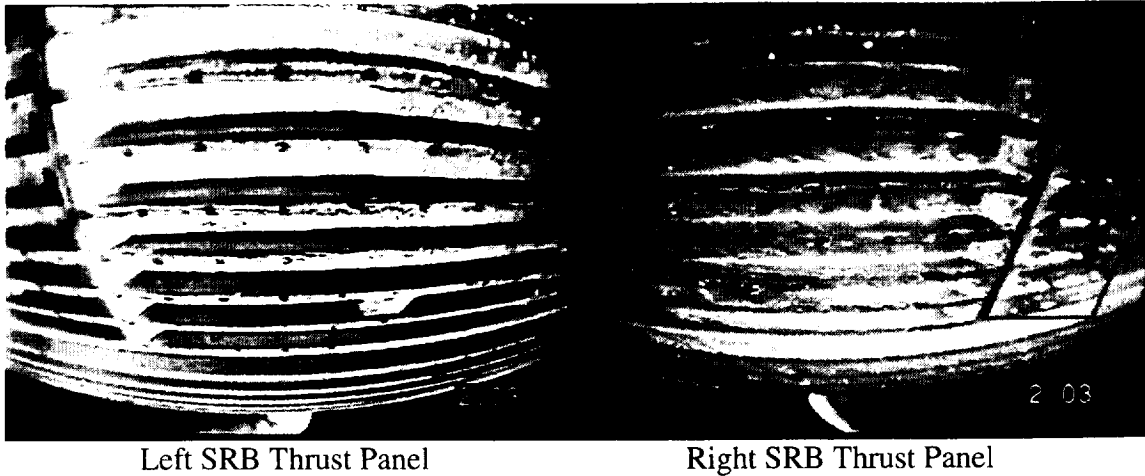


Figure 2.6 (A) ET Thrust Panel Views Prior to Separation

Figure 2.6(A) contains views of the STS-101 ET Thrust Panels just before SRB separation (2:03 seconds MET). After separation, there were a large number of divots visible in the unvented area of the right ET thrust panel aft and in the -Y direction from the RSRB attach fitting (area outlined in red on the right SRB thrust panel view). The largest of these divots were estimated to be less than 5-inches in diameter. Six divots were seen on a right thrust panel circumferential rib (station XT-1058). A seventh divot was seen on the same circumferential rib in the +Y direction closer to the +Y intertank.



Figure 2.6(B) Divot on -Y LH2-to-intertank Flange Closeout





## Summary of Significant Events

An approximate 9-inch divot was seen on the -Y LH2-to-intertank flange closeout and the LH2 tank interface aft of the intertank access door (Figure 2.6(B)).

Several small divots were seen on the +Y/-Z intertank rib heads during the SRB separation. Multiple pieces of small white-colored debris were seen moving throughout the field of view during SRB separation on both of the thrust panel video views.

Based on a visual comparison between the STS-101 views and the previous mission STS-103 thrust panel video, both of the STS-101 thrust panels appeared to contain more visible divots than the STS-103 video views of the respective thrust panels.

### 2.7 LANDING SINK RATE ANALYSIS

Image data from the centerline film camera at the approach end of runway 33 was used to determine the landing sink rate of the main gear. In the analysis, data from approximately one second of imagery immediately prior to touchdown was considered. Data points defining the main gear struts were collected on every frame (101 frames of the data during the last second prior to touch down). An assumption was made that the line of sight of the camera was perpendicular to the Orbiter's y-axis. The distance between the main gear struts was used as a scaling factor. The main gear height above the runway was calculated by the vertical difference between the main gear struts and a reference point on the runway. A trendline was determined considering the height of the Orbiter above ground with respect to time. The sink rate equals the slope of this regression line.

The left main gear sink rate for STS-101 landing at one second, at half a second, and at a one quarter of a second are provided in Table 2.7. A plot describing these sinkrates is shown in Figure 2.7.

Time Prior to Touchdown	Left Main Gear Sink Rate	Estimated Error (1 $\sigma$ )
1.00 Sec.	1.9 ft/sec	$\pm 0.1$ ft/sec
0.50 Sec.	2.2 ft/sec	$\pm 0.1$ ft/sec
0.25 Sec.	2.8 ft/sec	$\pm 0.2$ ft/sec

Right Main Gear Touchdown = 150:06:20:17:960 (UTC)

Table 2.7 Main Gear Landing Sink Rate



## Summary of Significant Events

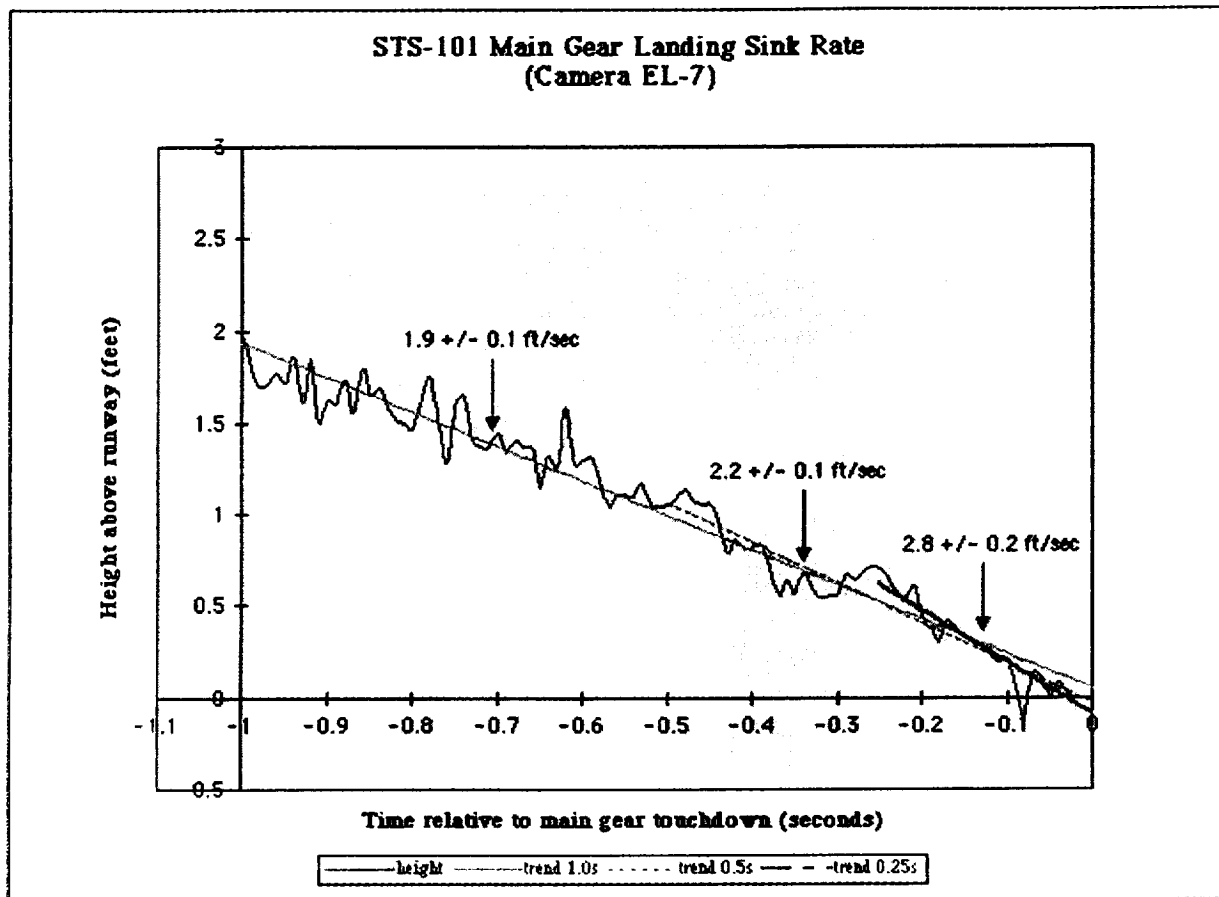


Figure 2.7 Main Gear Landing Sink Rate

The maximum allowable main gear sink rate values are 9.6 feet/second for a 212,000 lb. vehicle and 6.0 feet/second for a 240,000 lb. vehicle. The landing weight of the STS-101 vehicle was estimated to be 226,131 lbs.

## 2.8 OTHER

### 2.8.1 Normal Events

- elevon motion prior to liftoff
- RCS paper debris from SSME ignition through liftoff
- ET twang
- ice and vapor from the LO2 and LH2 TSM T-0 umbilical prior to and after disconnect
- multiple pieces of ET/Orbiter umbilical ice debris falling along the body flap during liftoff
- vapor off the SRB stiffener rings
- acoustic waves in the exhaust cloud during liftoff



## **Summary of Significant Events**

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- debris in the exhaust cloud after liftoff
- expansion waves after liftoff
- charring of the ET aft dome
- ET aft dome outgassing
- roll maneuver
- linear optical effects
- recirculation
- SRB plume brightening
- SRB slag debris before, during, and after SRB separation

### **2.8.2 Normal Pad Events**

Normal pad events observed included:

- hydrogen burn ignitor operation
- FSS and MLP deluge water activation
- sound suppression system water operation
- GH2 vent arm retraction
- TSM T-0 umbilical operations
- LH2 and LO2 TSM door closures



## **APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY**







# **Space Shuttle Mission STS-101**

## **Engineering Photographic Analysis Summary Report Marshall Space Flight Center**

*Prepared: June 21, 2000*

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**STS-101**  
**Engineering Photographic Analysis Summary Report**  
**Marshall Space Flight Center**

**CONTENTS**

<b>1. STS-101 ENGINEERING PHOTOGRAPHIC ANALYSIS.....</b>	<b>1</b>
<b>2. PHOTOGRAPHIC COVERAGE .....</b>	<b>1</b>
<b>3. INDIVIDUAL CAMERA ASSESSMENTS:.....</b>	<b>1</b>
3.1 VIDEO CAMERA ASSESSMENTS.....	1
3.2 FILM CAMERA ASSESSMENTS.....	2
<b>4. T-ZERO TIMES .....</b>	<b>3</b>
<b>5. SRB SEPARATION TIMING.....</b>	<b>3</b>
<b>6. OBSERVATIONS: .....</b>	<b>4</b>
6.1 VIDEO CAMERA OTV070 (A) .....	4
6.2 VIDEO CAMERA OTV070 (B).....	5
6.3 VIDEO CAMERA TV-12 .....	6
6.4 FILM CAMERA E223 .....	7
6.5 FILM CAMERA E207 .....	8
6.6 LEFT SRB VIDEO CAMERA .....	9
6.7 RIGHT SRB VIDEO CAMERA .....	10
6.8 ON BOARD HAND HELD CAMERA( ET -Y SIDE).....	11
6.9 ON BOARD HAND HELD CAMERA(ET TOP VIEW) .....	12
6.10 ON BOARD HAND HELD CAMERA( ET +Y SIDE ).....	13
6.11 FILM CAMERA FL-102 .....	14
6.12 ASTRONAUT HAND HELD VIDEO CAMERA .....	15
6.13 UMBILICAL WELL 35MM STILL CAMERA .....	16
<b>7. ANALYSES.....</b>	<b>17</b>
7.1 STS-101: -Y THRUST PANEL.....	17
7.2 STS-101: +Y THRUST PANEL.....	20
7.3 STS-101: THRUST PANEL COMPARISON .....	23

## TABLES

Table 1 . Camera Coverage.....	1
Table 2. T-Zero Times.....	3
Table 3. STS-101 -Y Thrust Panel: Vented and Non-Vented Foam Loss Events .....	17
Table 4. STS-101 -Y Thrust Panel: Foam Loss Events by Category.....	17
Table 5. STS-101 +Y Thrust Panel: Vented and Non-Vented Foam Loss Events .....	20
Table 6. STS- 101 +Y Thrust Panel: Foam Loss Events by Category .....	20

## FIGURES

Figure 1. Free Burning Hydrogen at SSME Start-Up.....	4
Figure 2. Ice Strikes SSME#3 Nozzle .....	5
Figure 3. Debris Induced Streak Observed by Video Camera TV-12.....	6
Figure 4. Debris Induced Streak Observed by Film Camera E212.....	7
Figure 5. Debris Streak Observed by Film Camera E207.....	8
Figure 6. Left SRB Video Camera .....	9
Figure 7. Right SRB Video Camera .....	10
Figure 8. View of -Y side of the ET from On-board 35mm Hand-held Camera .....	11
Figure 9. View of Top Side of the ET from On-board 35mm Hand-held Camera .....	12
Figure 10. View of -Y side of the ET from On-board 35mm Hand-held Camera .....	13
Figure 11. Ring shaped Debris Object Observed After SRB Separation .....	14
Figure 12. Selected Views from the Astronaut Hand Held Video.....	15
Figure 13 Umbilical Well 35mm Still Camera.....	16
Figure 14. STS-101 -Y Thrust Panel .....	18
Figure 15. STS-101 -Y Thrust Panel: Foam Loss Event Timeline .....	18
Figure 16. STS-101 -Y Thrust Panel: Foam Loss Timeline for Vented and Non-Vented Areas.....	19
Figure 17. STS-101 -Y Thrust Panel: Foam Loss Timeline for Categories of Events .....	19
Figure 18. STS-101 +Y Thrust Panel .....	21
Figure 19. STS-101 +Y Thrust Panel: Foam Loss Event Timeline .....	21
Figure 20. STS-101 +Y Thrust Panel: Foam Loss Timeline for Vented and Non-Vented Areas.....	22
Figure 21. STS-101 +Y Thrust Panel: Foam Loss Timeline for Categories of Events .....	22
Figure 22. Foam Loss Comparison for -Y Thrust Panels.....	23
Figure 23. Foam Loss Comparison for +Y Thrust Panels.....	24
Figure 24. Comparison of Foam Loss Events from all SRB Cameras.....	24

## 1. STS-101 Engineering Photographic Analysis

The launch of Space Shuttle Mission STS-101, the twenty-first flight of the Orbiter Atlantis (OV-104) occurred May 19, 2000, at approximately 5:11 AM Central Daylight Time from launch complex 39A, Kennedy Space Center (KSC), Florida. Launch time reported as 140:10:11:09.994 Universal Time Coordinated (UTC) by the MSFC Flight Evaluation Team.

Photographic and video coverage has been evaluated to determine proper operation of the flight hardware. Additional information concerning photographic analysis of this and previous space shuttle missions is available on the MSFC Engineering Photographic Analysis website at URL:

<http://photo4.msfc.nasa.gov/STS/sts.html>.



## 2. Photographic Coverage

Video and high-speed film cameras providing this coverage are located on the fixed service structure (FSS), mobile launch platform (MLP), perimeter sites, Eastern Test Range tracking sites and onboard the vehicle. Seventy-one engineering photographic products consisting of launch video, ground-based engineering films and video and onboard film and video were received and reviewed at MSFC.

The view from two video cameras, OTV041 and OTV048, became overexposed at liftoff. The focus on film camera E13 was soft and the frame rate on film camera E20 was slow. Overall, good coverage of the launch was obtained. Video from the Left and Right SRB cameras was very good. Film from the 16mm umbilical camera FL102 was not received. Camera coverage received at MSFC for STS-101 is illustrated in the following table.

**Table 1 . Camera Coverage**

Camera Location	16mm	35mm	Video
MLP	19	0	4
FSS	5	0	3
Perimeter	0	7	6
Tracking	0	10	11
Onboard	1	2	3
Totals	25	19	27

The Photographic Acquisition Document Data (PADD) and information regarding individual camera status and assessments may be found on the website.

## 3. Individual Camera Assessments:

Notable assessments for individual cameras are listed below. The complete assessments for all individual cameras for flight STS-101 may be found on the website.

### 3.1 Video Camera Assessments

TV5            Glowing debris particles ejected from SRB plume prior to separation.



TV12      Glowing debris particles ejected from SRB plume prior to separation. Debris induced streak in SSME plumes at 140:10:12:03.2 UTC. SRB separation time at 140:10:13:13.75 UTC.

TV13      Glowing debris particles ejected from SRB plume after separation. Linear optical distortions noted. SRB separation time at 140:10:13:13.717 UTC.

ET204      Glowing debris particles ejected from SRB plume after separation.

ET207      Glowing debris particles ejected from SRB plume after separation. Debris-induced streak in SSME plume. Linear optical distortions noted. Fast-moving streak of unknown origin moves through field of view. White ring observed inside SSME#2 nozzle. These phenomena will be investigated more closely with high-speed film from cameras E2 and E19.

ET212      Glowing debris particles ejected from SRB plume after separation. Debris-induced streak observed in SSME plume.

TV21A      Free burning Hydrogen noted.

OTV009      Ice/frost from LH2 17-inch disconnect strikes the umbilical doorsill at engine start-up. No damage observed.

OTV041      Free burning Hydrogen observed near the drag chute compartment. Image becomes overexposed at lift-off.

OTV048      View overexposed at liftoff.

OTV051      Free burning Hydrogen strikes the drag chute door. Mach diamonds form in 3-2-1 order.

OTV054      Ice/frost impacts the LO2 umbilical doorsill.

OTV070      Free burning Hydrogen strikes the drag chute door. Two ice chunks from LO2 TSM strike SSME#3 near number 8 hatband.

OTV071      Free burning Hydrogen rises past drag chute door.

### **3.2 Film Camera Assessments**

E1      Free burning Hydrogen observed past aft edge of body flap.

E2      Free burning Hydrogen impinges on drag chute door.

E6      Vapors noted from ET-Orbiter aft vertical strut ET attach point.

E8      Holddown post M-2 PIC firing time at 140:10:11:10.003 UTC. Small debris particle appears to fall from hole in SRB holddown post foot.

E9      Holddown Post M-1 PIC firing time 140:10:11:10.001 UTC.

E12      Hold down Post M-5 PIC firing time 140:10:11:10.001 UTC.

E13      Holddown Post M-6 PIC firing time 140:10:11:10.001 UTC. Camera experienced soft focus.

E16      Free burning Hydrogen observed. Thermal curtain flexing observed at SRB ignition.

E17      Free burning Hydrogen observed. Noticeable ice/frost from LO2 T-0 umbilical noted.

E18      Free burning Hydrogen observed. Noticeable ice/frost from LH2 T-0 umbilical. Chipped tiles noted on aft base heat shield.

E19      Hot wall of SSME#2 appears nominal from this camera angle. Ice impacts SSME#3 nozzle. Free burning Hydrogen impinges on drag chute door.

E20      Free burning Hydrogen impinges on drag chute door. Camera frame rate is approximately 55 fps as opposed to the 400 fps expected.

E33      Ice/frost falls from GUCP prior to and after separation.

E34      Ice/frost from GUCP noted falling alongside ET. Vapors from rudder/speed brake observed.

E52      Debris-induced streaks in SSME plume. Free burning Hydrogen impinges on drag chute door.

E62      Free burning Hydrogen observed.

E63      Free burning Hydrogen observed.

E204      Glowing debris particles ejected from SRB plume after separation. Vehicle obscured by clouds several times early in flight. OMS burn noted after SRB separation.

E205      Glowing debris particles ejected from SRB plume after separation. Debris-induced streak in SSME plume. Flow recirculation noted. OMS burn noted after SRB separation.

E207      Debris-induced streak in SSME plume. Linear optical distortions noted. Flow recirculation noted. Debris of unknown origin appears to be located near orbiter between inboard orbiter elevon and right SRB. Light colored ring noted on hot wall of SSME#2 nozzle approximately halfway up the engine nozzle.

- E208      Glowing debris particles ejected from SRB plume after separation. Linear optical distortions noted. OMS burn noted after SRB separation.
- E212      Debris-induced streaks observed in SSME plume.
- E220      Glowing debris particles ejected from SRB plume after separation. Debris-induced streak in SSME plume. OMS burn noted after SRB separation. Light colored ring noted on hot wall of SSME#2 nozzle.
- E222      Debris induced streak in SSME plumes at 140:10:12:03.299 UTC.
- E223      Debris-induced streaks in SSME plume. Debris ejected from SRB plume during ascent.
- FL102     The -Y Thrust Panel is in shadow and +Y Thrust Panel is at an oblique view, no divots are noticeable on the Thrust Panels. Object shaped like a ring was observed moving aft, from top to bottom through field of view.

#### 4. T-Zero Times

T-Zero times are determined from MLP cameras that view the SRB holddown posts numbers M-1, M-2, M-5, and M-6. These cameras record the explosive bolt combustion products.

**Table 2. T-Zero Times**

Holddown Post	Camera Position	Time (UTC)
M-1	E9	140:10:11:10.001
M-2	E8	140:10:11:10.003
M-5	E12	140:10:11:10.001
M-6	E13	140:10:11:10.001

#### 5. SRB Separation Timing

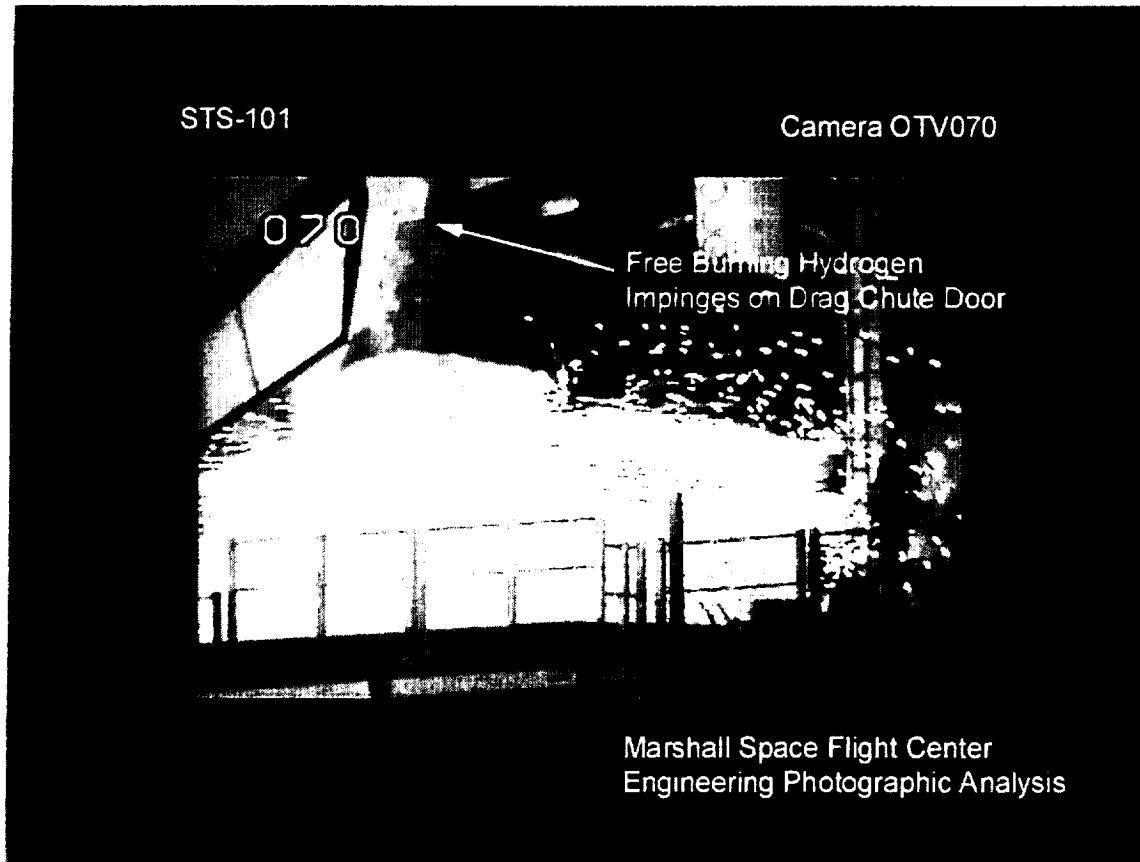
SRB separation time, as recorded by observations of the BSM combustion products from long-range film camera E207, occurred at approximately 140:10:13:13.726 UTC.



## 6. Observations:

### 6.1 Video Camera OTV070 (A)

Free burning Hydrogen was observed, as a glowing reddish-orange gas, at engine start-up. This is a typical occurrence at start-up. The free burning Hydrogen was noted in this instance to impinge on the drag chute door as shown in the figure below.

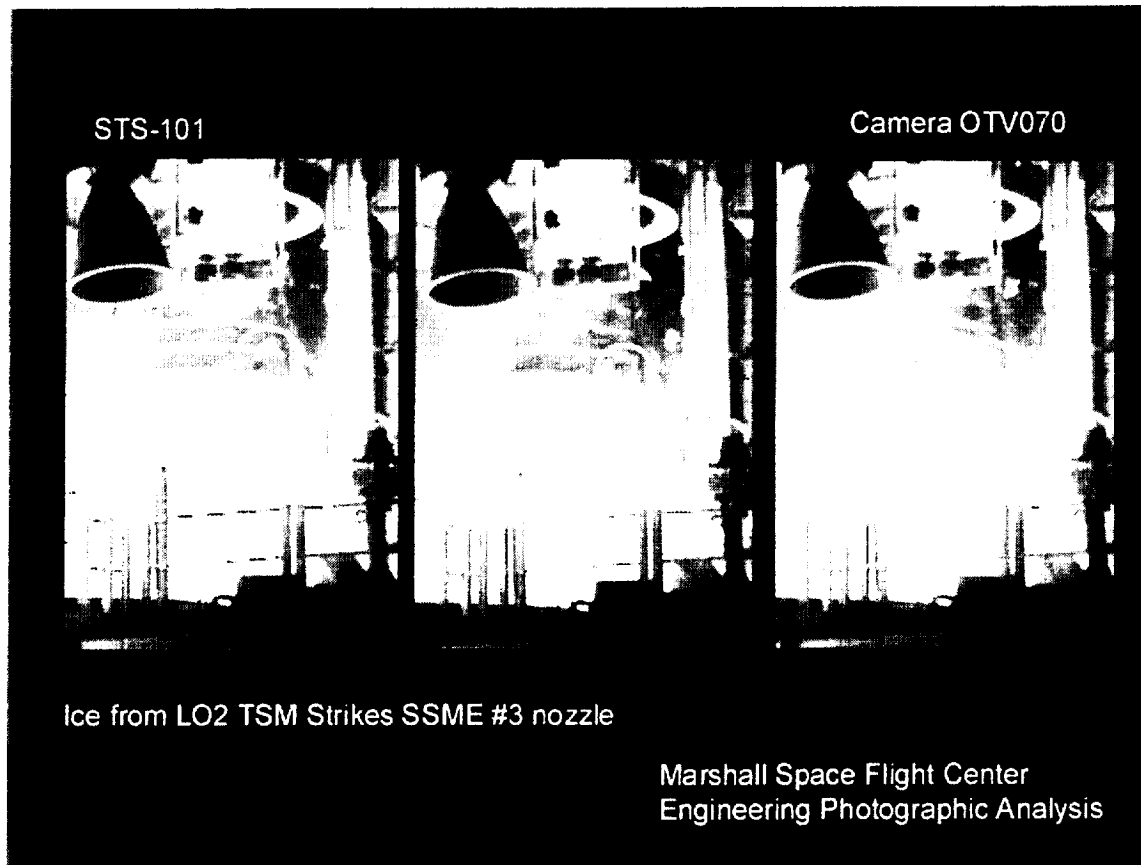


**Figure 1. Free Burning Hydrogen at SSME Start-Up**



## 6.2 Video Camera OTV070 (B)

Two pieces of ice debris from the LO2 TSM impacted SSME#3 nozzle near the eighth hatband. Images below show one of the ice masses impacting SSME#3 nozzle and breaking apart. No damage to the nozzle was observed from either ice impact.

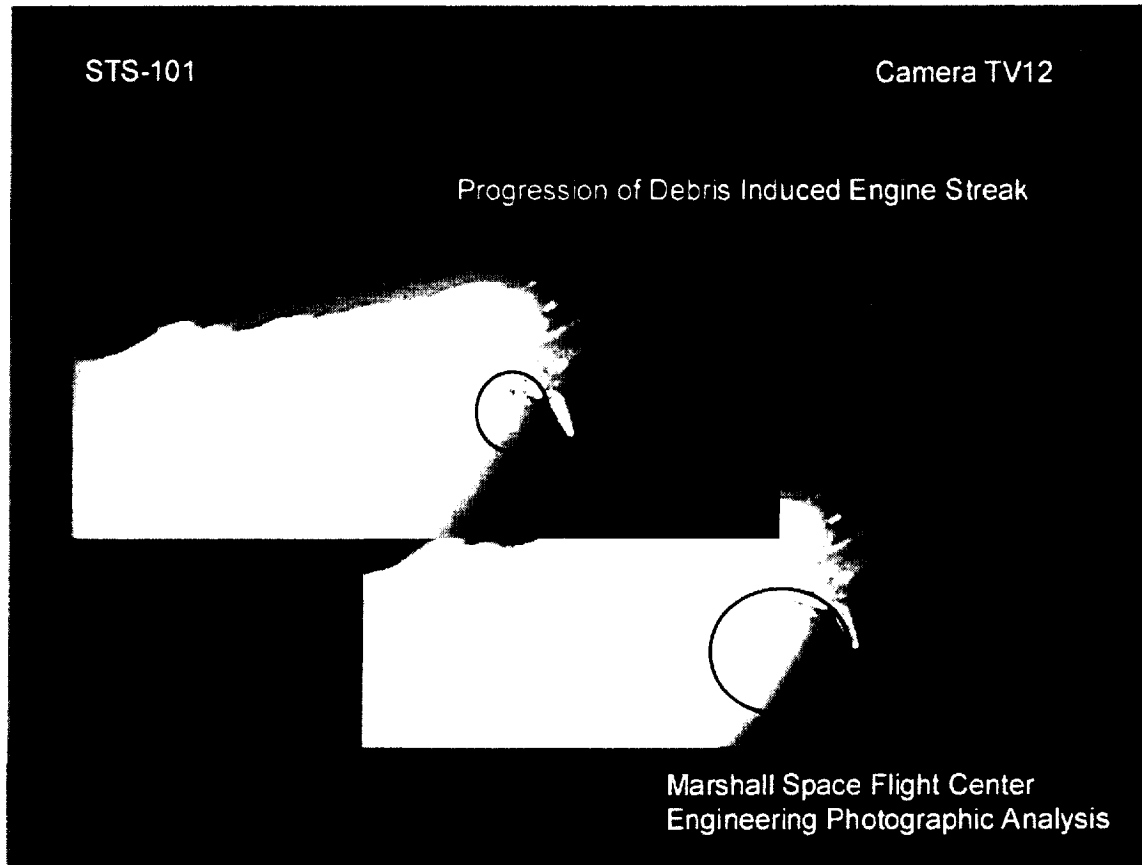


**Figure 2. Ice Strikes SSME#3 Nozzle**



### 6.3 Video Camera TV-12

A view from video camera TV12 of the debris induced streak in the SSME plumes. These debris induced streaks are typically the result of butcher paper or purge barrier material falling into a plume.

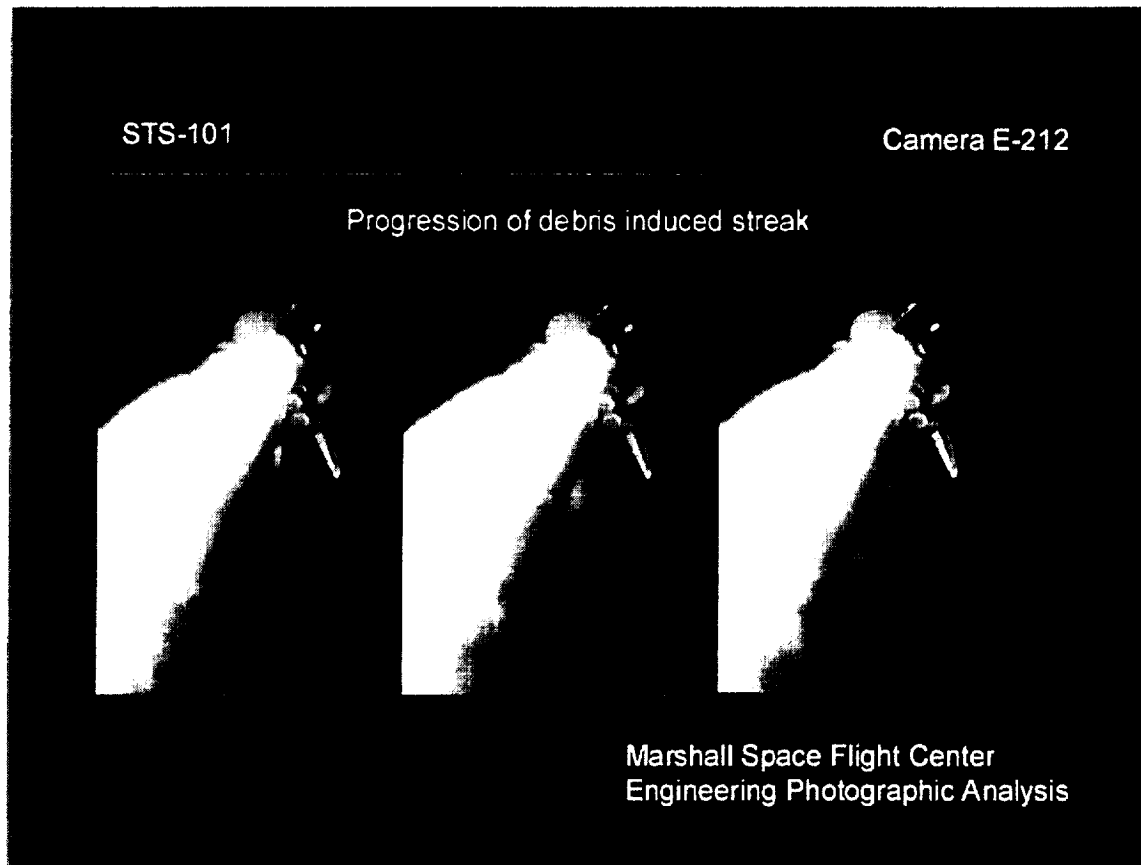


**Figure 3. Debris Induced Streak Observed by Video Camera TV-12**



#### **6.4 Film Camera E223**

A sequence of frames from the 35mm Film Camera E212 showing the debris induced streak originating in the SSME plumes. This is the same streak as shown in figure 3. The film cameras typically give better resolution of events. In the sequence of frames below, the streak can be seen originating in the plume at a distance from the nozzle. This separation from the nozzle exit plane is an indicator that a streak is caused by debris falling into the plume.



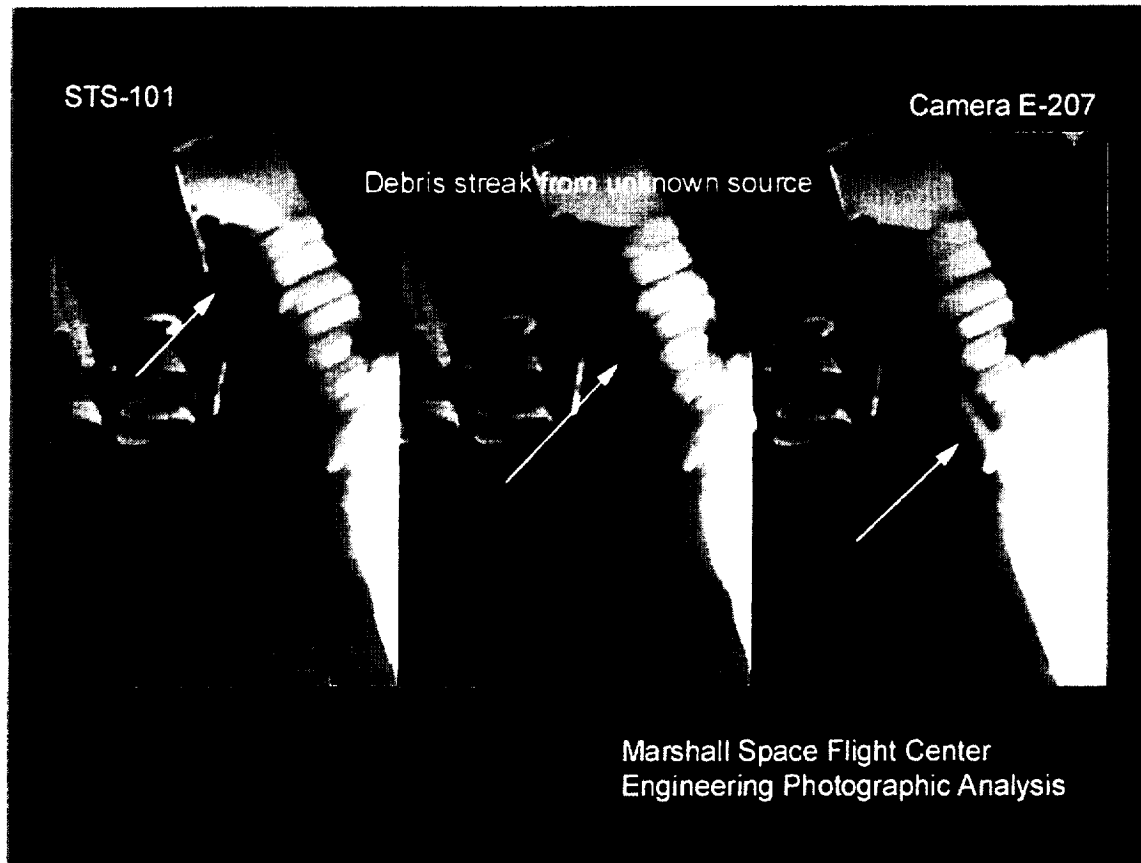
**Figure 4. Debris Induced Streak Observed by Film Camera E212**





### 6.5 Film Camera E207

A sequence of images from the 35mm Film Camera E207 that shows debris of unknown origin that caused a streak, not associated with plume streaking, which appears to be located near orbiter between inboard orbiter elevon and right SRB. This event was timed at 140:10:11.44.148 UTC. A similar event occurred on STS-26. The STS-26 event was identified as debris from tiles. Inspection of tiles after landing revealed a damage site which is suspected as the cause of this streak.



**Figure 5. Debris Streak Observed by Film Camera E207**



### 6.6 Left SRB Video Camera

Views of the External Tank from the left Solid Rocket Booster Video Camera early (0:16), just before (2:03) and just after (2:04) separation from vehicle, showing a progression of the condition of the Thermal Protective Surface on the -Y Thrust Panel.

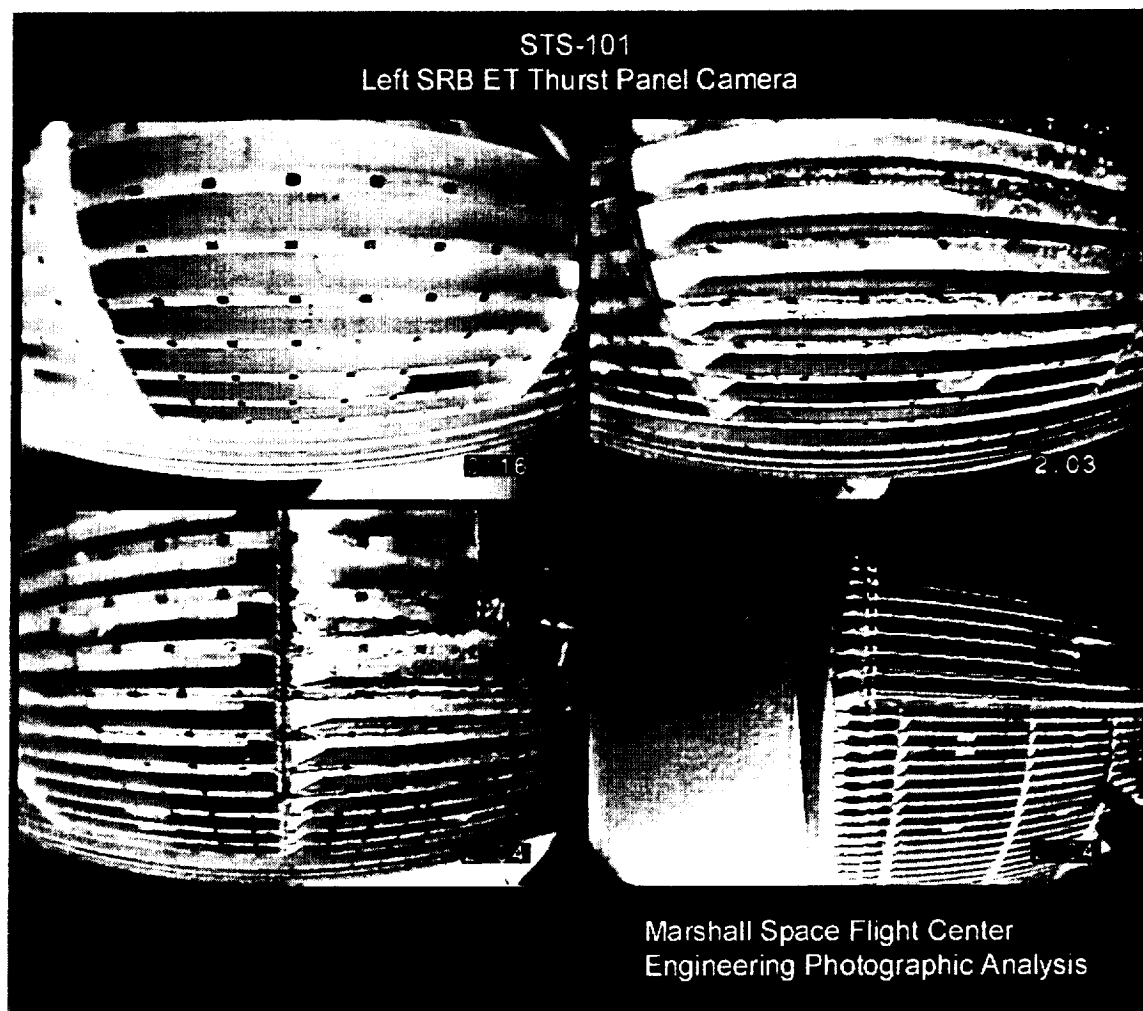


Figure 6. Left SRB Video Camera



### 6.7 Right SRB Video Camera

Views of the External Tank from the right Solid Rocket Booster Video Camera early (0:13), just before (2:03) and just after (2:04) separation from vehicle, showing a progression of the condition of the Thermal Protective Surface (TPS) on the +Y Thrust Panel.

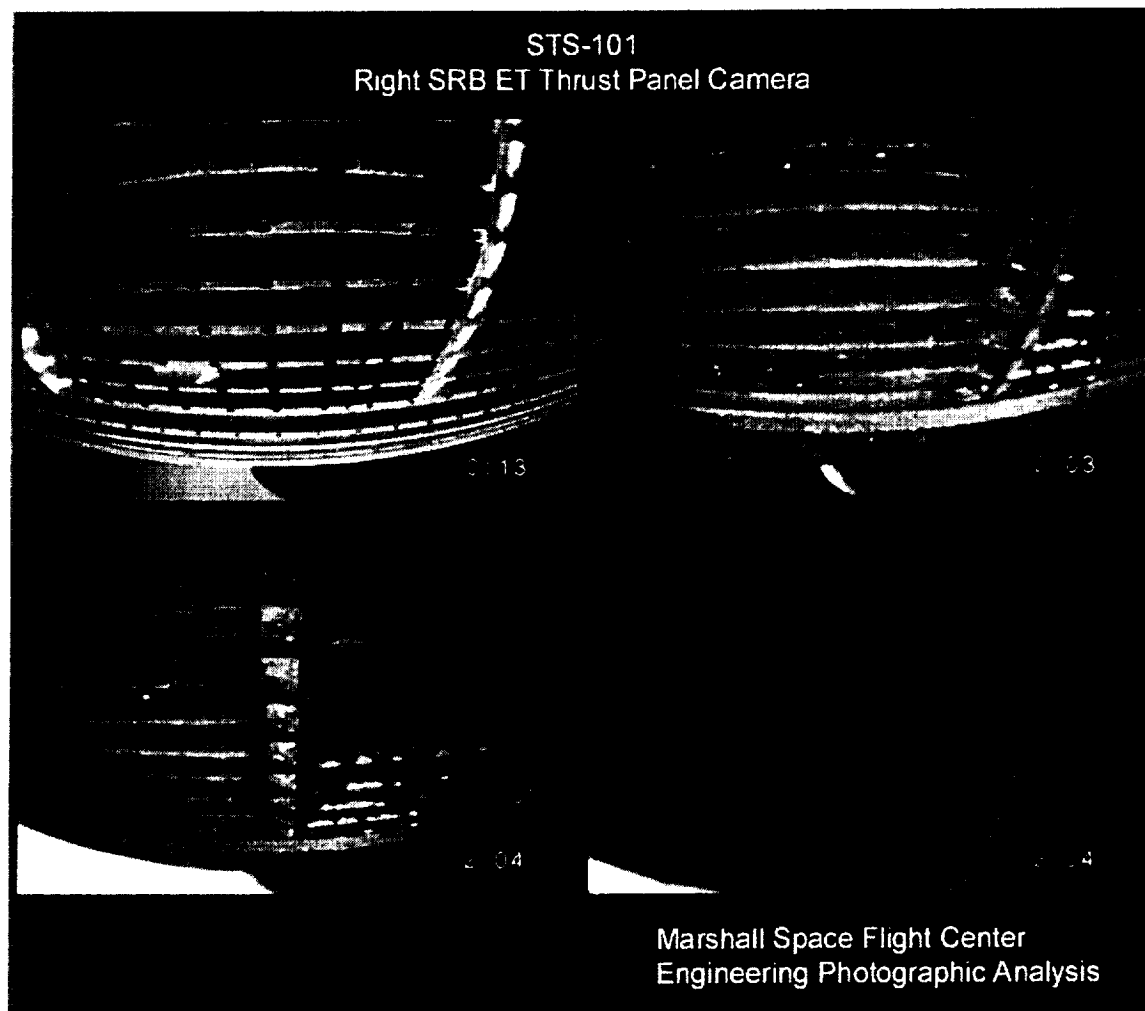
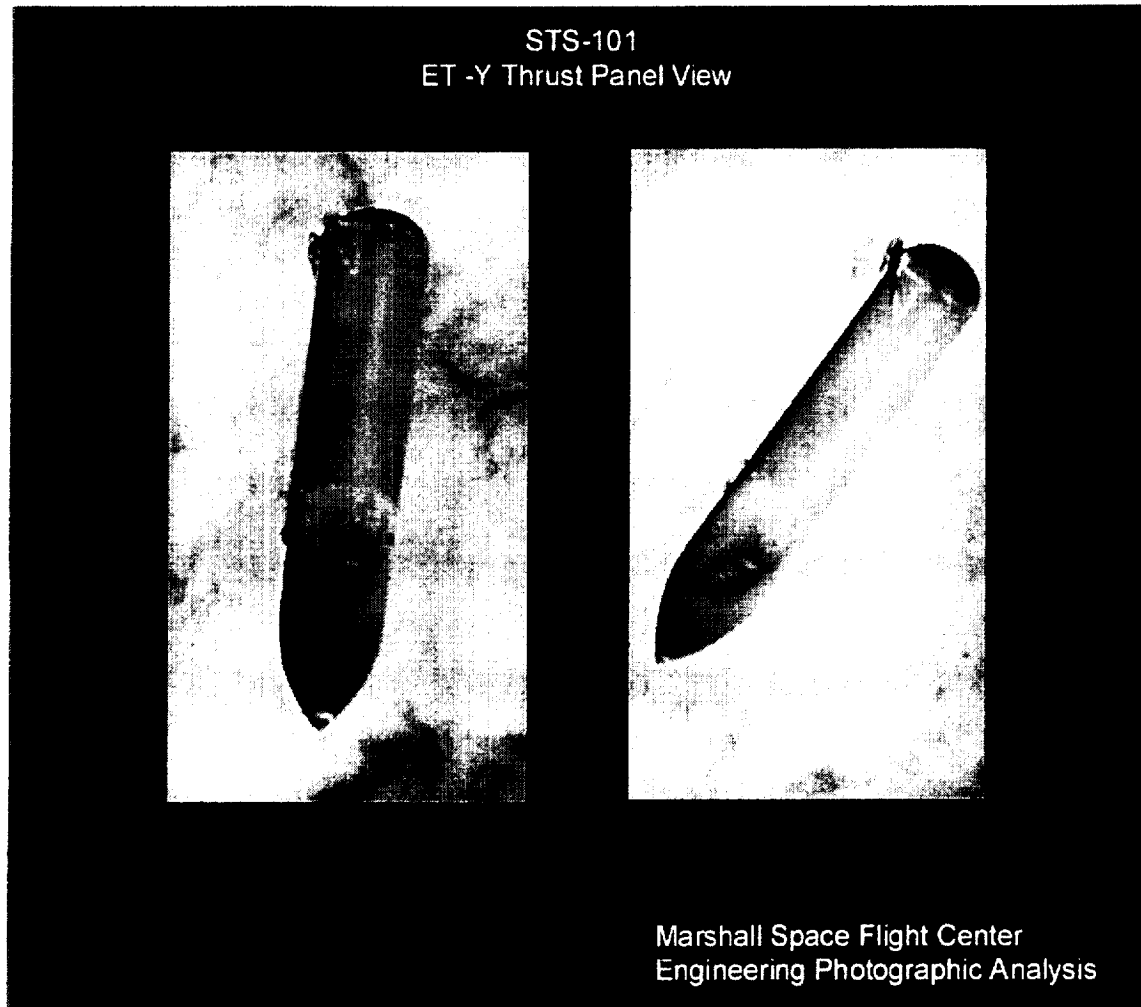


Figure 7. Right SRB Video Camera



#### **6.8 On Board Hand Held Camera( ET-Y Side)**

Views of the -Y side of External Tank (ET) after separation from vehicle, showing the condition of the Thermal Protective Surface (TPS). No obvious or large scale TPS divoting is observed, scarring of TPS from BSM motor firing appears normal.



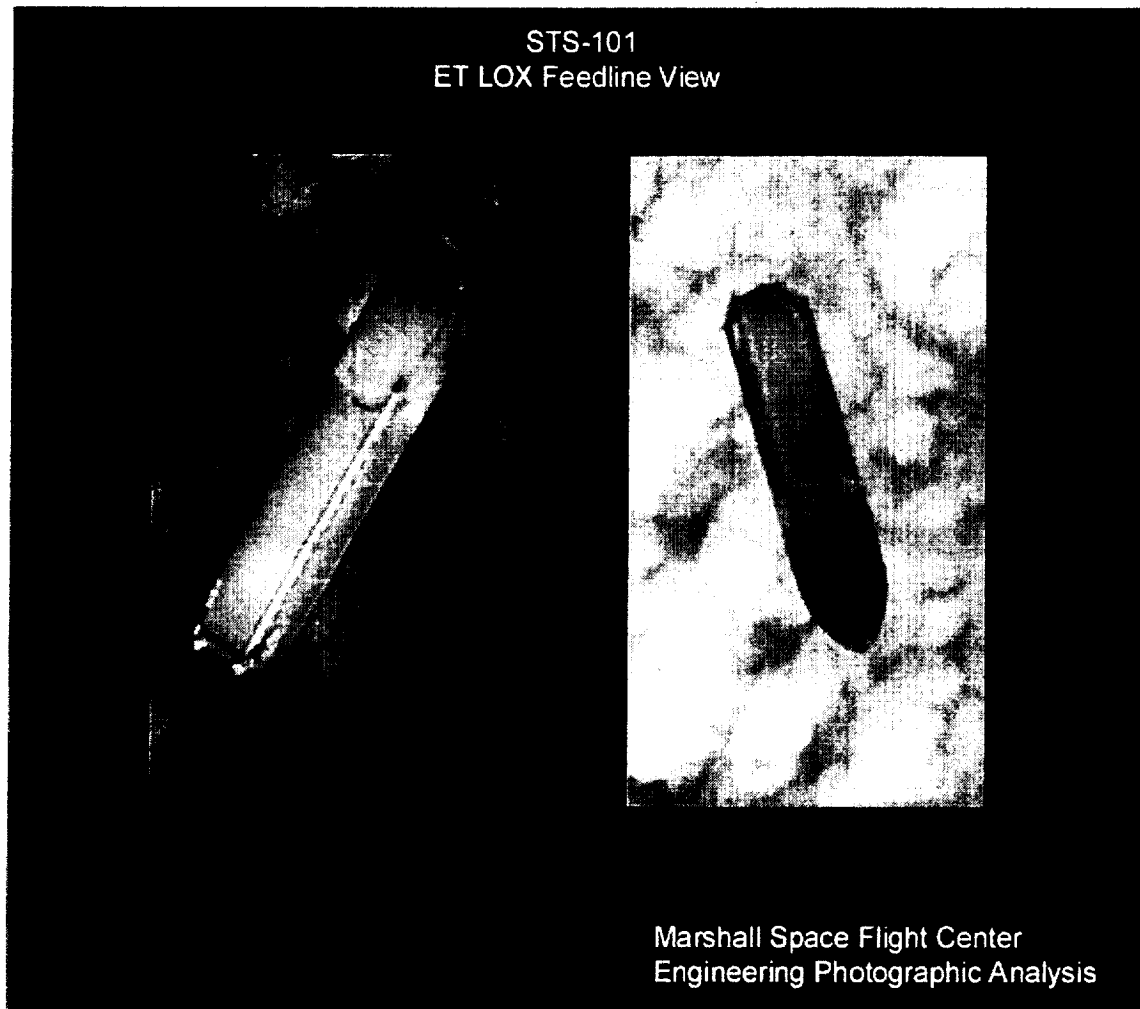
**Figure 8. View of -Y side of the ET from On-board 35mm Hand-held Camera**





#### **6.9 On Board Hand Held Camera(ET Top View)**

Views of the top side of External Tank (ET) after separation from vehicle, showing the LO2 Feedline and the condition of the Thermal Protective Surface (TPS). No obvious or large scale TPS divoting is observed, scarring of TPS from BSM motor firing appears normal.

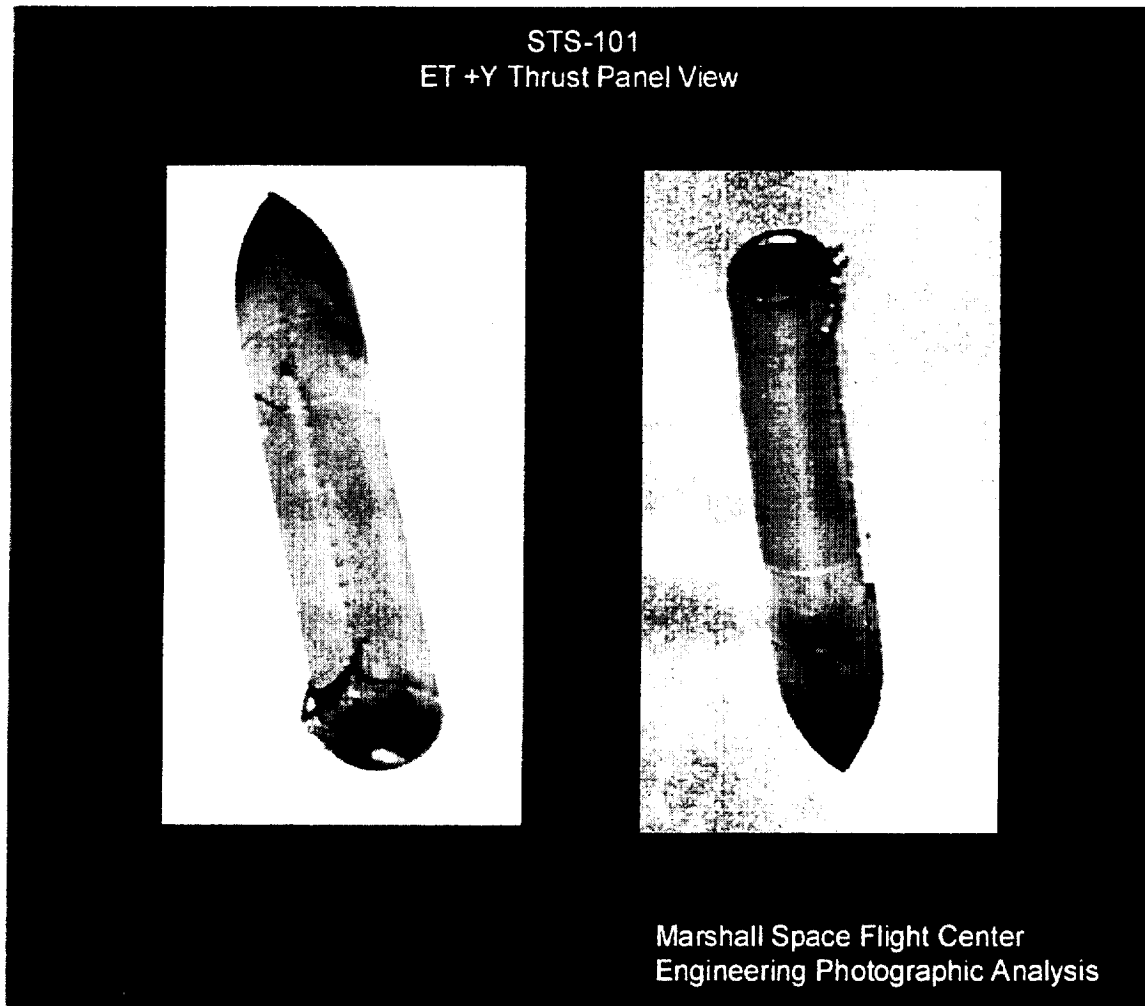


**Figure 9. View of Top Side of the ET from On-board 35mm Hand-held Camera**



**6.10 On Board Hand Held Camera ( ET +Y Side )**

Views of the +Y side of External Tank (ET) after separation from vehicle, showing the condition of the Thermal Protective Surface (TPS). No obvious or large scale TPS divoting is observed, scarring of TPS from BSM motor firing appears normal. Charring of the TPS on the aft dome of the LOX tank appears normal.

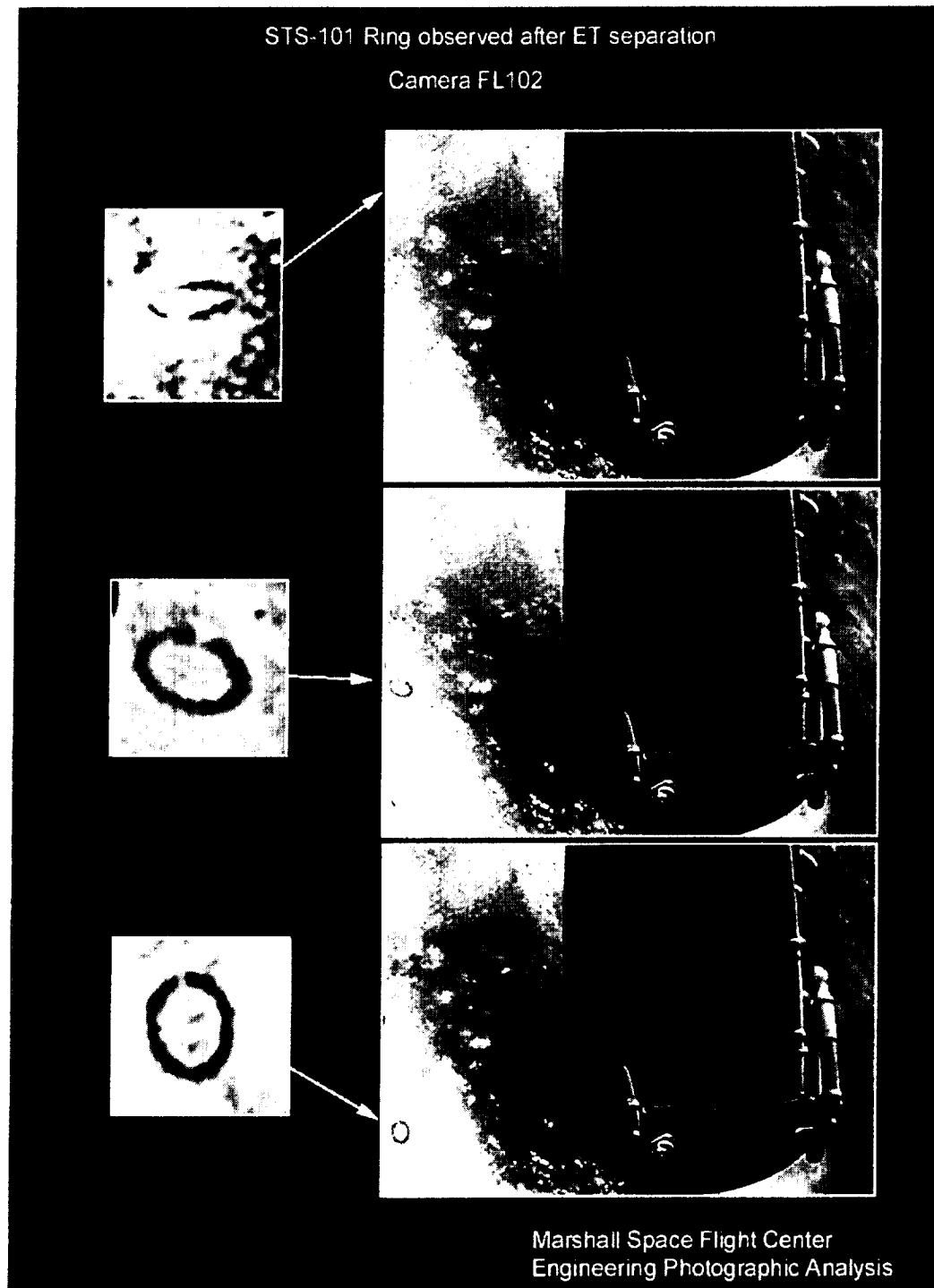


**Figure 10. View of -Y side of the ET from On-board 35mm Hand-held Camera**



### 6.11 Film Camera FL-102

A ring-shaped debris object was noted moving from top to bottom of the field of view after SRB separation. The object was out of focus, indicating that it was near the camera, rather than the ET. It is suspected that the object is an O-ring from one of the 17" disconnects.

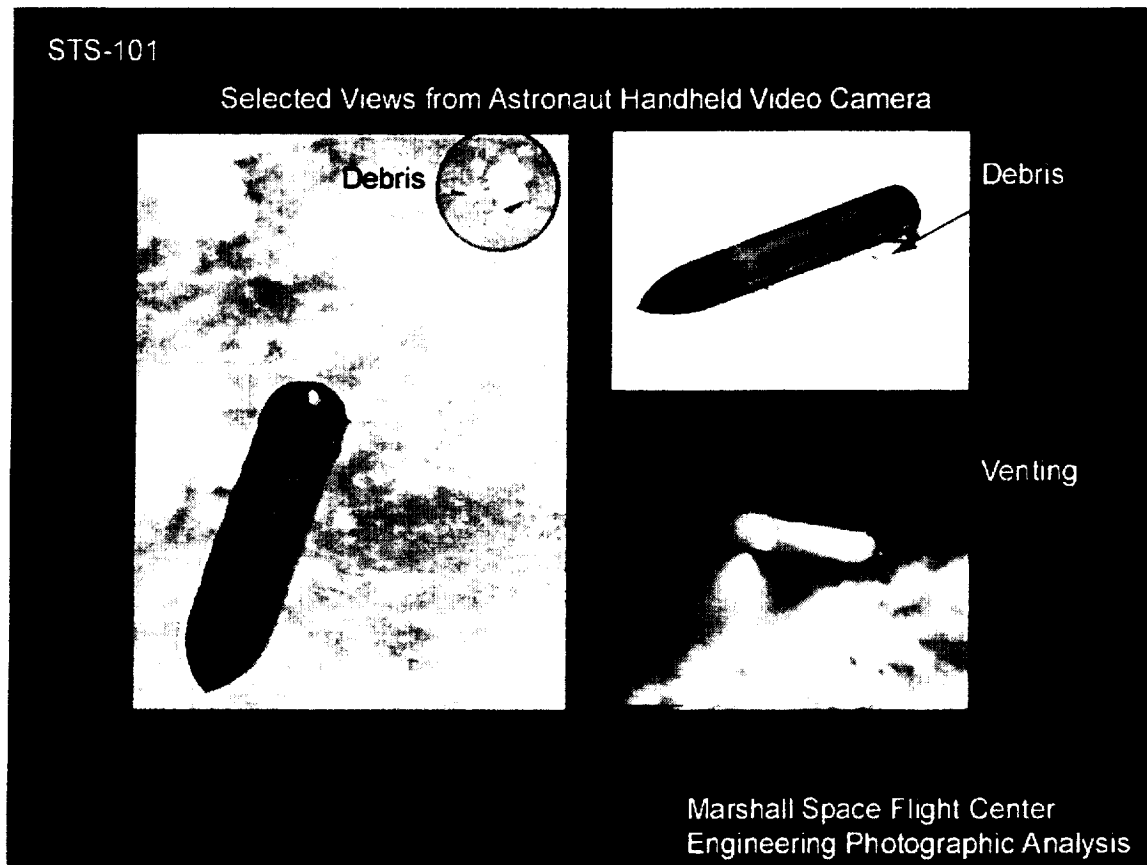


**Figure 11. Ring shaped Debris Object Observed After SRB Separation**



### 6.12 Astronaut Hand Held Video Camera

Two conspicuous debris objects were observed from the astronaut hand held video. One was an odd shaped debris item, noted in the upper right corner of the left hand frame below and appears to be ice. The other debris object is most likely ice floating between the camera and the ET. Typical GUCP venting was also observed.



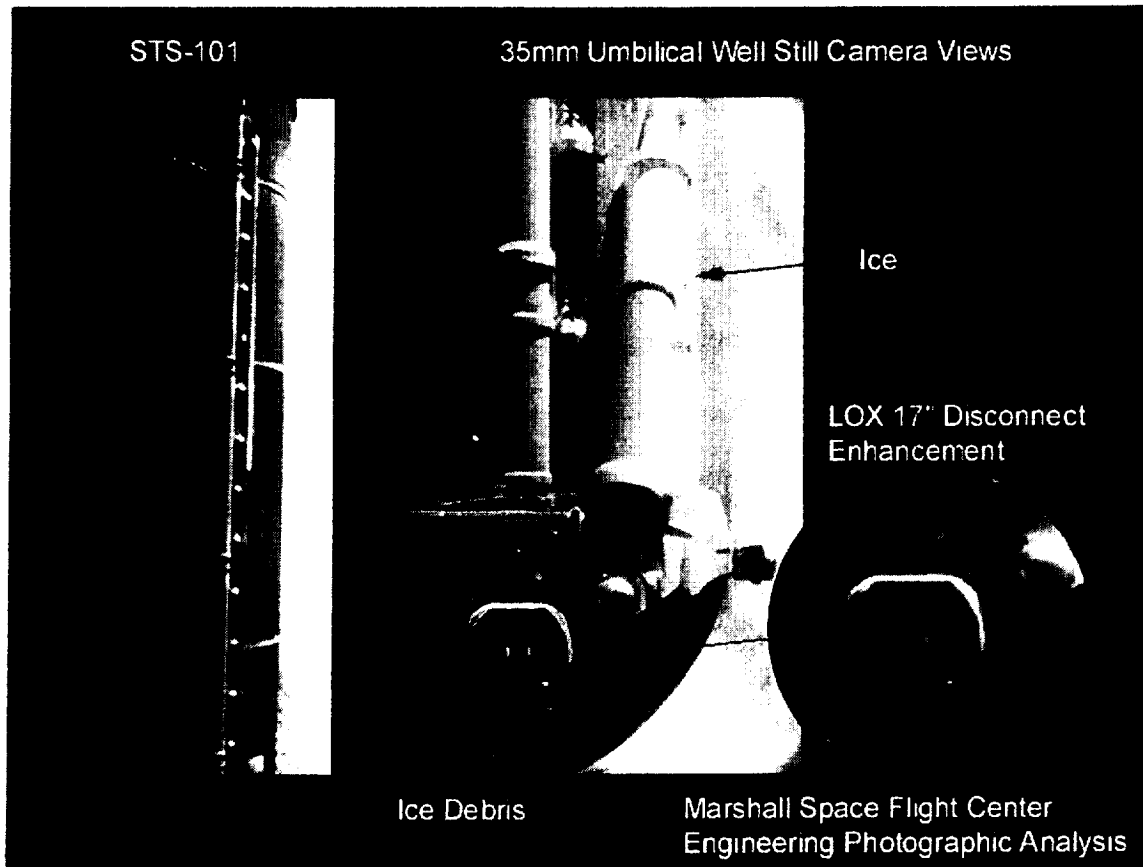
**Figure 12. Selected Views from the Astronaut Hand Held Video**





### 6.13 Umbilical Well 35mm Still Camera

Ice was observed on the ET after separation, as noted in the frame below. Because of a late +X translation, the forward portion of the ET was not imaged by the still camera. Image fog degraded several of the last exposures on the 35mm film roll, creating a reddened cast to the images.



**Figure 13 Umbilical Well 35mm Still Camera**



## 7. Analyses

STS-101 carried video cameras on both the left and right SRBs. The purpose of the video cameras was to document TPS foam loss events occurring on the ET thrust panels. ET thrust panel TPS has been vented as a device to reduce both the size and the amount of foam loss events. The SRB videos, examples in Figure 6 and Figure 7, were analyzed to determine the quantity and location of foam loss events on the +Y and -Y ET thrust panels. The results of these analyses are presented below.

### 7.1 STS-101: -Y Thrust Panel

Figure 14 illustrates all tabulated foam loss events on the -Y Thrust Panel of the ET for flight STS-101. White lines in the figure enclose vented areas. There were 100 total foam loss events recorded. The number of events recorded during each 0.5 second time interval and the total number of events from approximately T+90.0 seconds are shown in Figure 15. Using a fourth order polynomial approximation to trend the count data, the maximum foam loss activity appears to peak just after T+ 110.0 seconds. The maximum number of events recorded during any 0.5 second time interval was seven. Figure 16 and Table 3 compare vented and non-vented areas.

**Table 3. STS-101 -Y Thrust Panel: Vented and Non-Vented Foam Loss Events**

Category	Count
Vented	95
Non-Vented	5
<b>Total</b>	<b>100</b>

Figure 17 illustrates the timeline for accumulated foam loss in each category and Table 4 shows the final count for each category.

**Table 4. STS-101 -Y Thrust Panel: Foam Loss Events by Category**

Category	Count
Valley	42
Stringer	4
Longitudinal Rib	53
Circumferential Rib	0
Hi-Lock	0
Ramp	1
<b>Total</b>	<b>100</b>



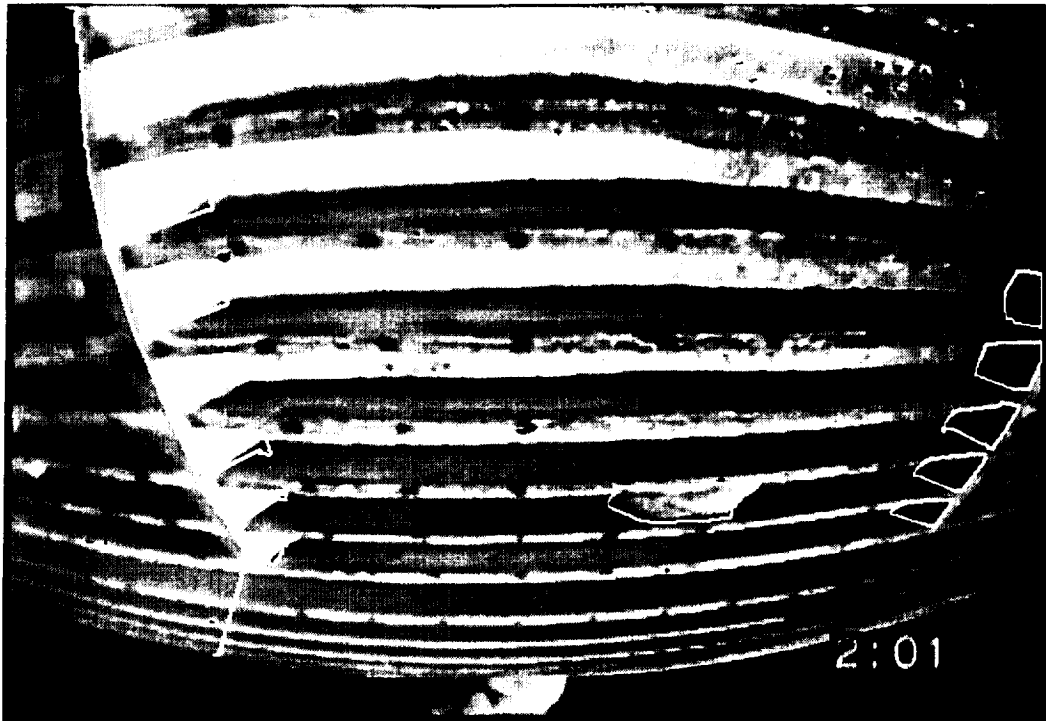


Figure 14. STS-101 -Y Thrust Panel

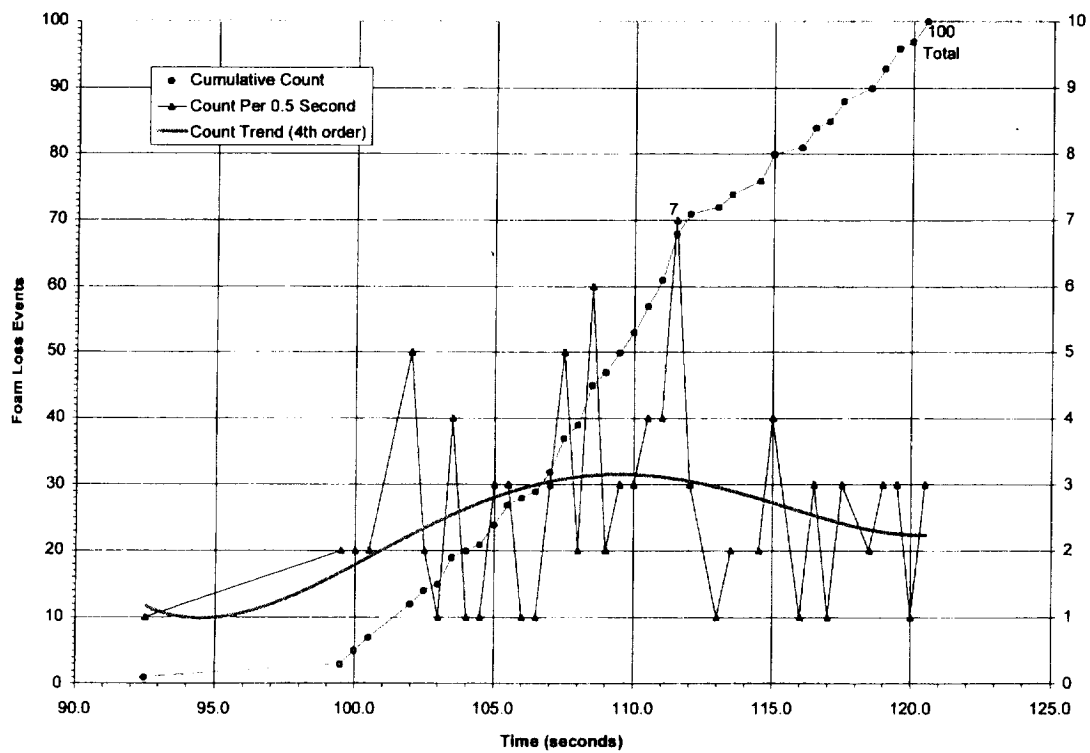
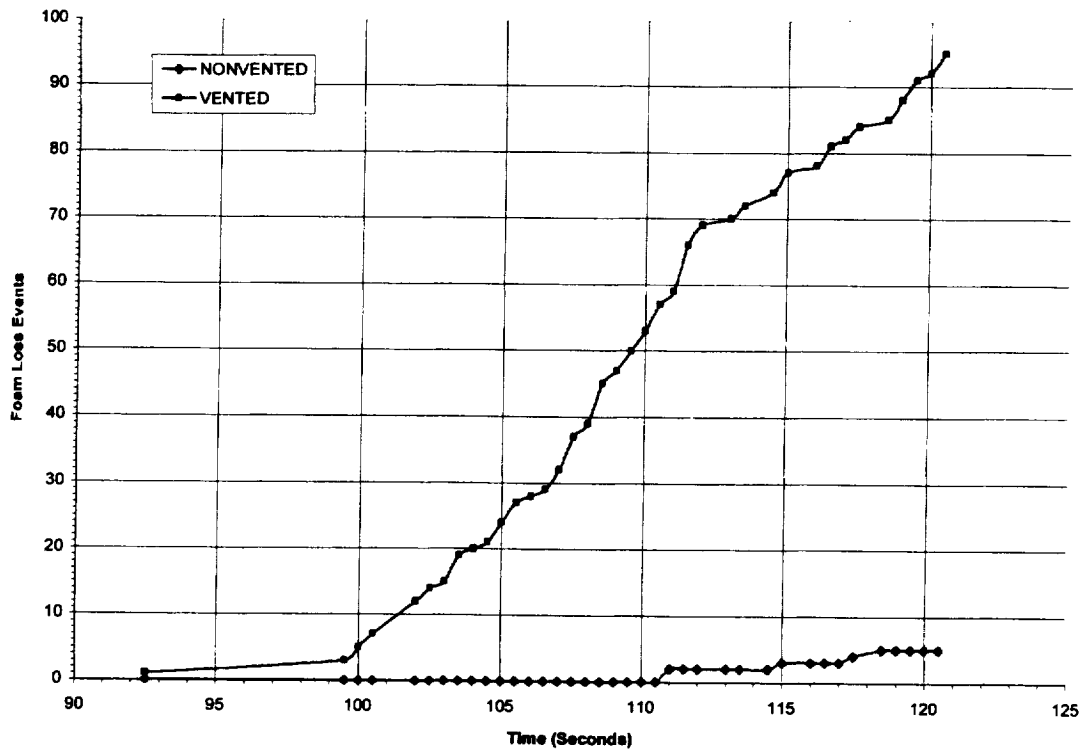
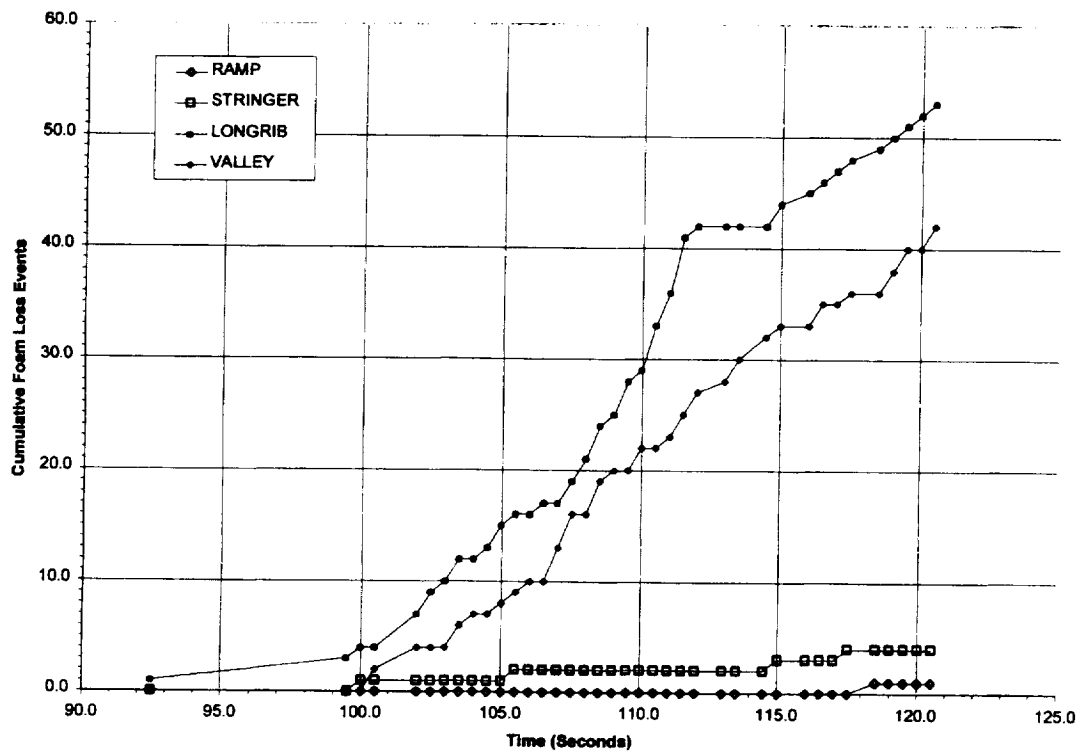


Figure 15. STS-101 -Y Thrust Panel: Foam Loss Event Timeline





**Figure 16. STS-101 -Y Thrust Panel: Foam Loss Timeline for Vented and Non-Vented Areas**



**Figure 17. STS-101 -Y Thrust Panel: Foam Loss Timeline for Categories of Events**

## 7.2 STS-101: +Y Thrust Panel

Figure 18 illustrates all tabulated foam loss events on the +Y Thrust Panel of the ET for flight STS-101. White lines in the figure enclose vented areas. There were 258 total foam loss events recorded. The number of events recorded during each 0.5 second time interval and the total number of events from approximately T+90.0 seconds are shown in Figure 19. Using a third order polynomial approximation to trend the count data, the maximum foam loss activity appears to peak at approximately T+ 110.0 seconds. The maximum number of events recorded during any 0.5 second time interval was 23. Table 5 and Figure 20 compare vented and non-vented areas.

**Table 5. STS-101 +Y Thrust Panel: Vented and Non-Vented Foam Loss Events**

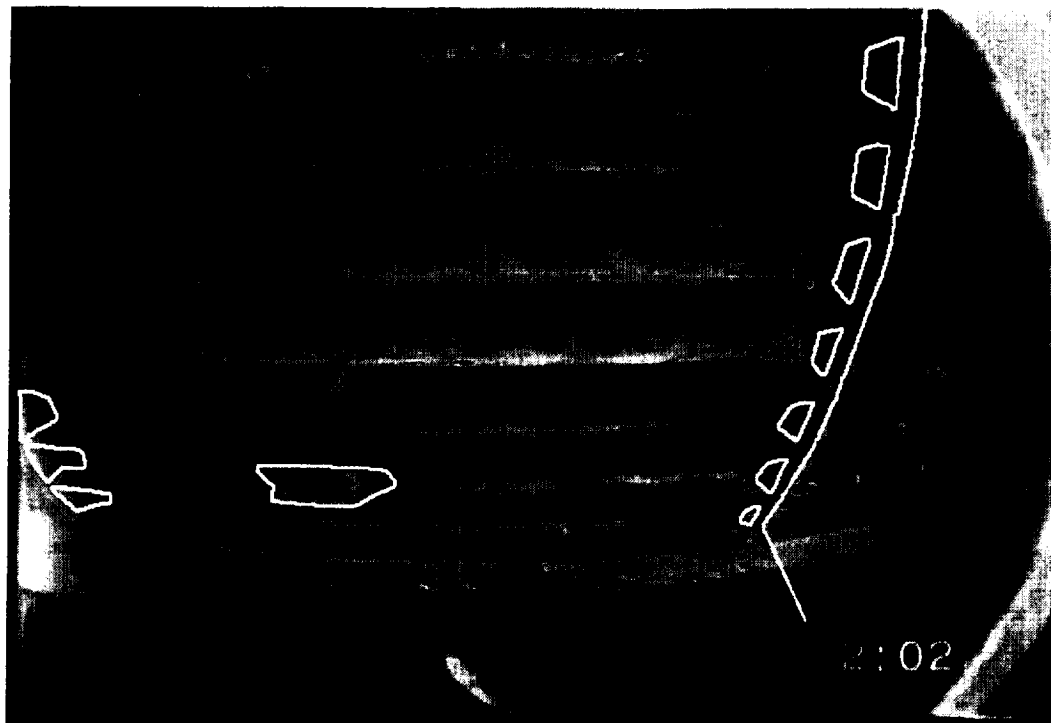
<b>Category</b>	<b>Count</b>
Vented	206
Non-Vented	52
<b>Total</b>	<b>258</b>

Figure 21 illustrates the timeline for accumulated foam loss in each category and Table 6 shows the final count for each category.

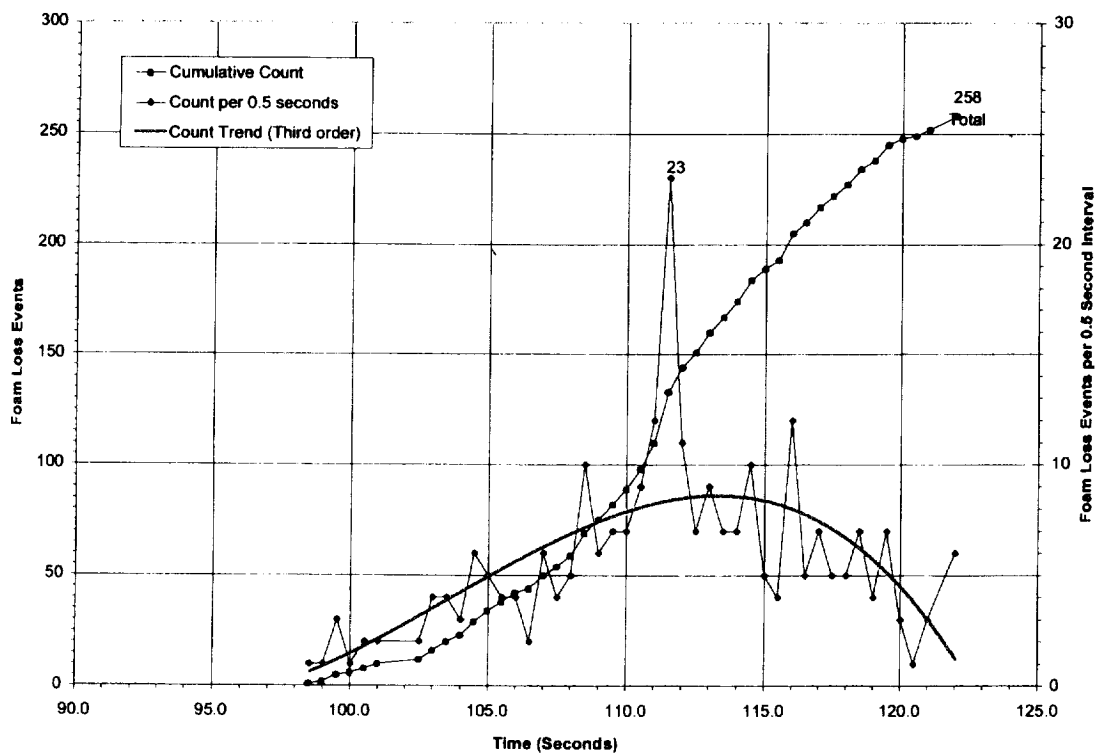
**Table 6. STS- 101 +Y Thrust Panel: Foam Loss Events by Category**

<b>Category</b>	<b>Count</b>
Valley	77
Stringer	35
Longitudinal Rib	132
Circumferential Rib	2
Hi-Lock	10
Ramp	2
<b>Total</b>	<b>258</b>



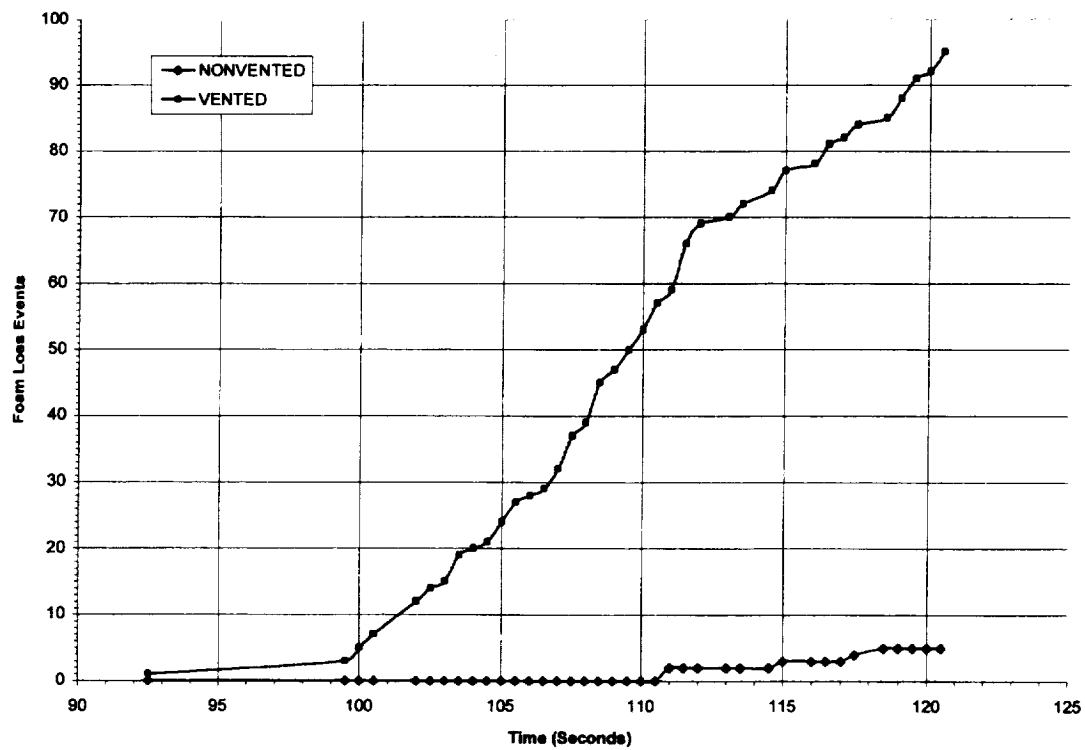


**Figure 18. STS-101 +Y Thrust Panel**

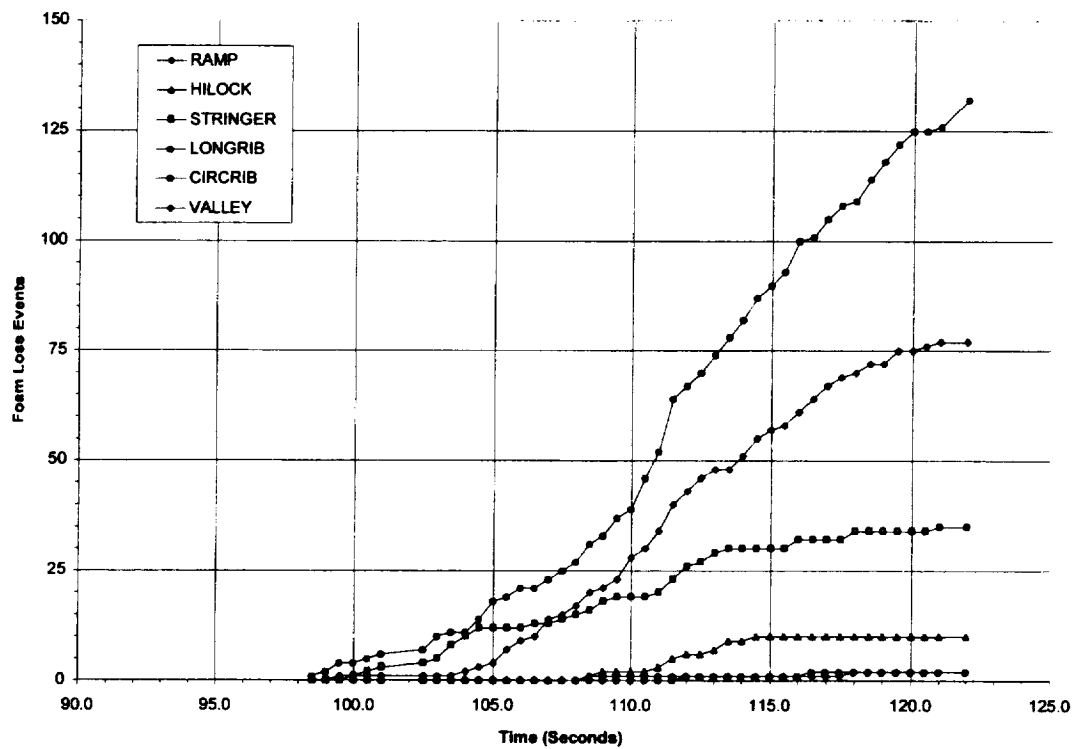


**Figure 19. STS-101 +Y Thrust Panel: Foam Loss Event Timeline**





**Figure 20. STS-101 +Y Thrust Panel: Foam Loss Timeline for Vented and Non-Vented Areas**



**Figure 21. STS-101 +Y Thrust Panel: Foam Loss Timeline for Categories of Events**

### 7.3 STS-101: Thrust Panel Comparison

Figure 22 and Figure 23 compare the number of foam loss events for each thrust panel recorded by each camera for each flight. STS-95 was not equipped with a camera to record the +Y thrust panel.

The foam loss events from the -Y thrust panels are bounded by a maximum of approximately 250 total events. The foam loss events from the +Y thrust panels are bounded by a maximum of approximately 650 total events. This maximum was achieved on mission STS-96 where a majority of the foam loss events recorded by the right SRB camera were noted to be in areas of the +Y thrust panel that were not vented.

No venting of the ET foam was performed for mission STS-95 and partial venting for STS-96 and STS-93. More extensive venting was done for Missions STS-103 and STS-101. The noticeable reduction in foam loss events in STS-103 and STS-101 is most probably attributable to the venting of more extensive areas of the thrust panels.

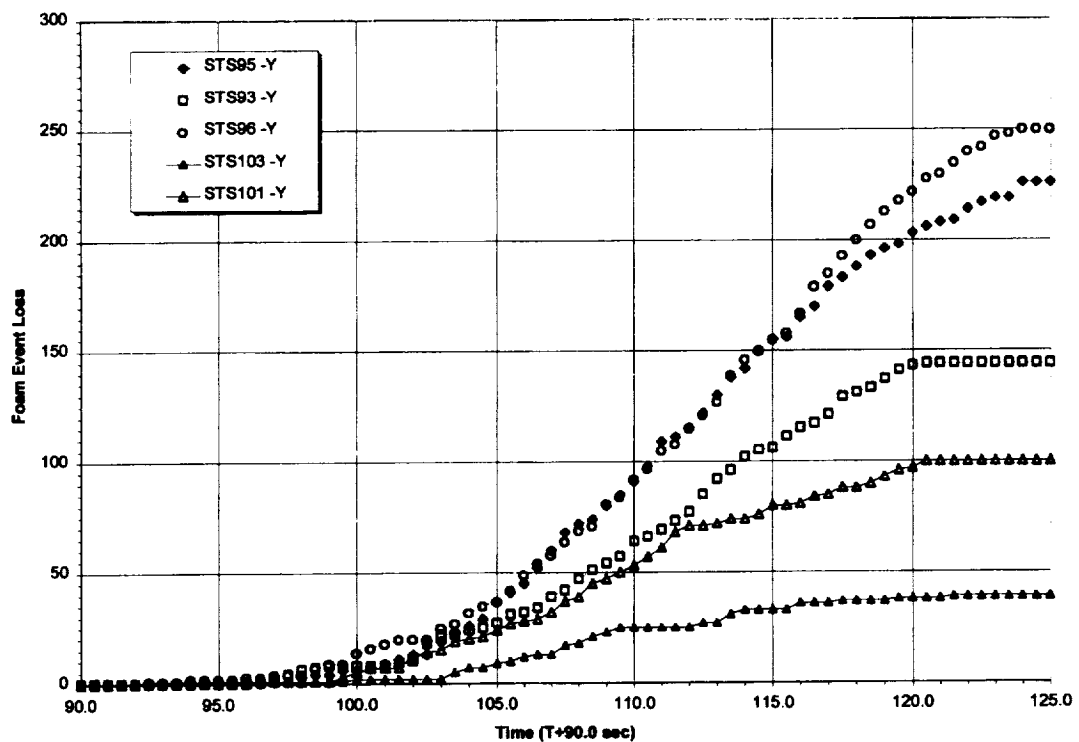


Figure 22. Foam Loss Comparison for -Y Thrust Panels

Figure 24 compares the number of foam loss events recorded by each camera for each flight. Most event timelines fall in the lower cluster, again, with only the STS-96 Right SRB camera recording the anomalous timeline.

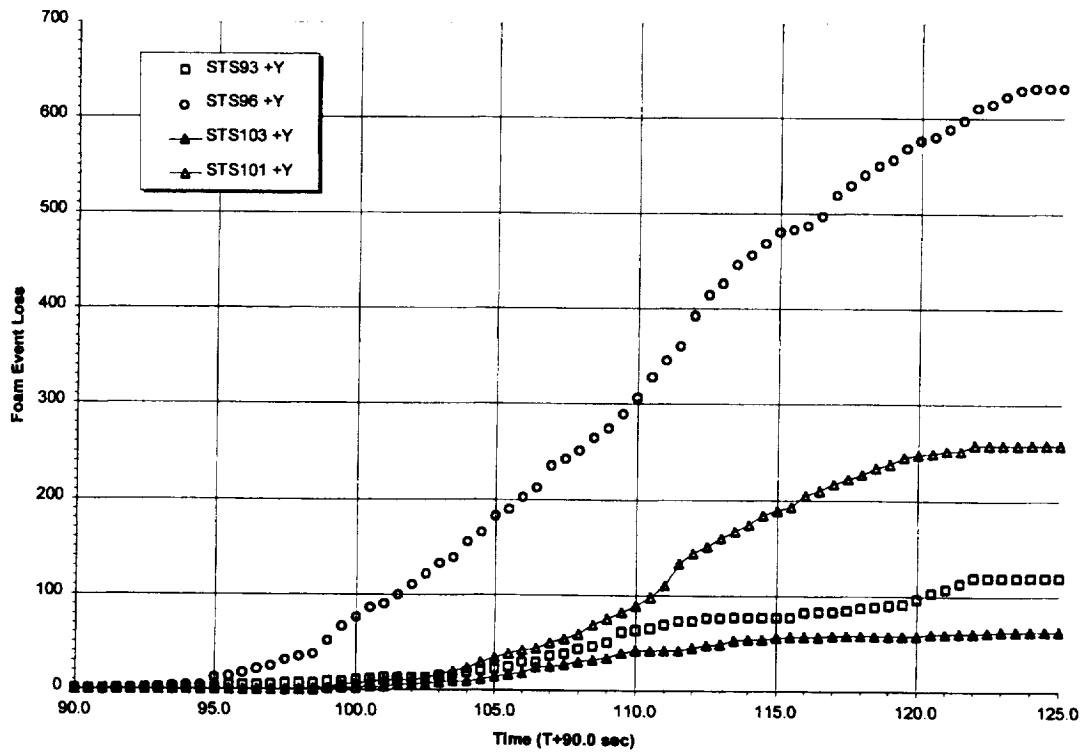


Figure 23. Foam Loss Comparison for +Y Thrust Panels

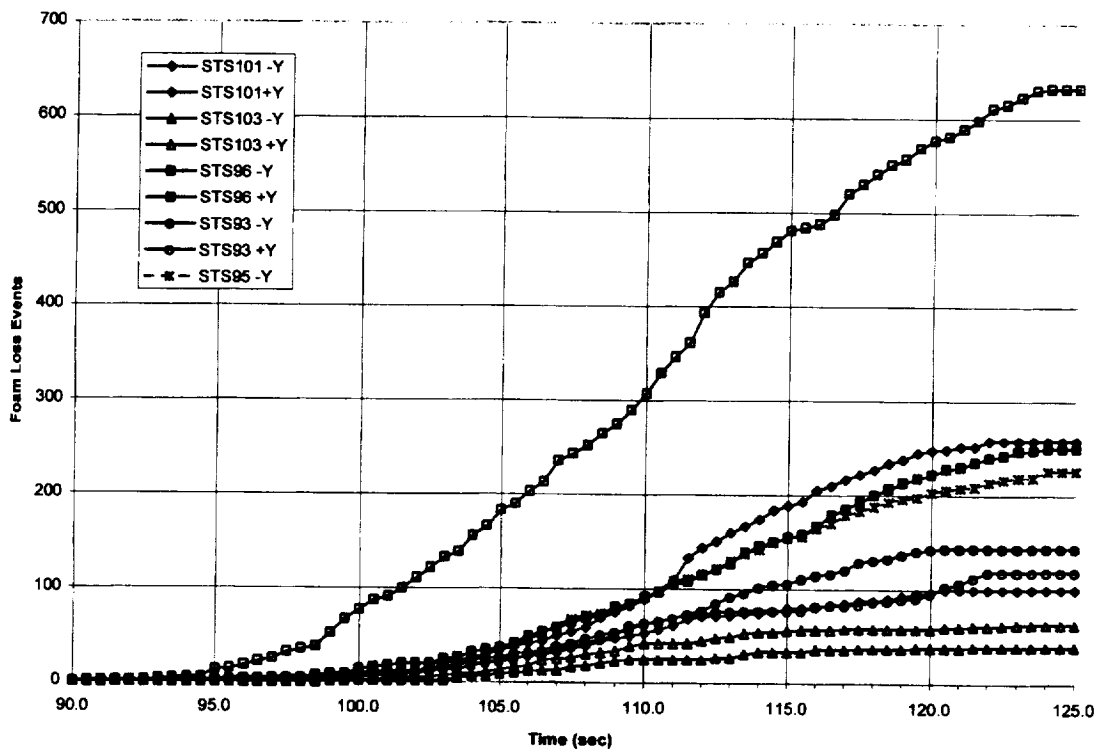


Figure 24. Comparison of Foam Loss Events from all SRB Cameras

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Tom Rieckhoff/TD53

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A debris/ice/thermal protection system assessment and integrated photographic analysis was conducted for Shuttle Mission STS-101. Debris inspections of the flight elements and launch pad were performed before and after launch. Icing conditions on the External Tank were assessed by the use of computer programs and infrared scanned data during cryogenic loading of the vehicle, followed by on-pad visual inspection. High speed photography of the launch was analyzed to identify ice/debris sources and evaluate potential vehicle damage and/or in flight anomalies. This report documents the ice/debris/thermal protection system conditions and integrated photographic analysis of Space Shuttle mission STS-101 and the resulting effect on the Space Shuttle Program.

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